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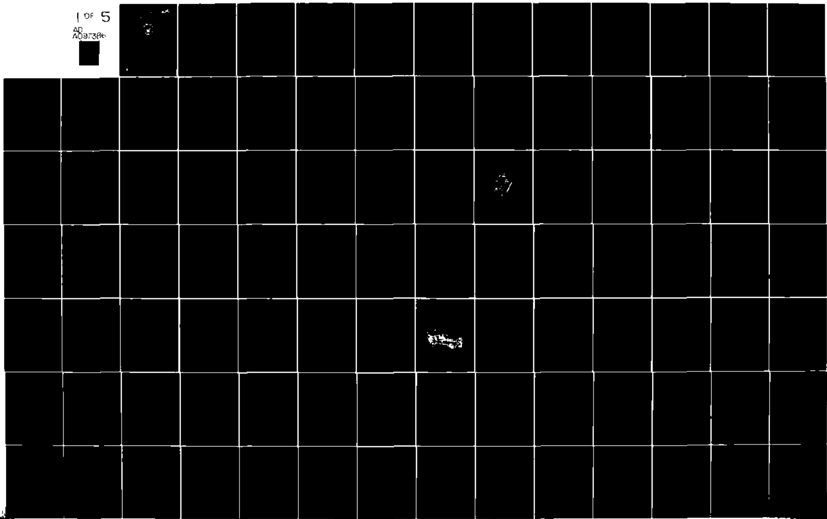

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Monterey, California

THESIS

UNITED STATES MARINE CORPS TACTICAL
COMMUNICATION ANTENNA SYSTEMS
OPERATIONAL PARAMETERS

by

William Patrick Keogh

December 1980

Thesis Advisor: S. Jauregui

Prepared for: Naval Ocean Systems Center
San Diego, California 92152

NAVAL POSTGRADUATE SCHOOL
Monterey, California

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The purpose of this analytical study was to develop useful computer models, using the Numerical Electromagnetic Code, for the VHF omnidirectional tactical antennas in the current inventory of the U.S. Marine Corps. The approach was to develop two basic models, one representing the RC-292 ground plane antenna, the other the MRC-109 vehicle mounted antenna system. With the solution of the current distributions on each of the models, calculations were made to analyze the impedance, gain and the associated radiation patterns

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United States Marine Corps Tactical Communication Antenna Systems Operational Parameters

by

William Patrick Keogh
Captain, United States Marine Corps
B.S.E.E., University of New Mexico, 1974

Submitted in partial fulfillment of the requirements for the degree of

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Author: William P. Keogh

Approved by: ______________________ Thesis Advisor

______________________ Second Reader

D. E. Kirk
Chairman, Department of Electrical Engineering

William M. Tolles
Dean of Science and Engineering

ABSTRACT

The purpose of this analytical study was to develop useful computer models, using the Numerical Electromagnetic Code, for the VHF omnidirectional tactical antennas in the current inventory of the U.S. Marine Corps. The approach was to develop two basic models, one representing the RC-292 ground plane antenna the other the MRC-109 vehicle mounted antenna system. With the solution of the current distributions on each of the models, calculations were made to analyze the impedance, gain and the associated radiation patterns for each of the antennas. Operation of these antennas over dissipative earth was also investigated.

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GLOSSARY

Za	Antenna Impedance = Rr ± jXa where: Rr=Antenna Radiation Resistance Xa=Antenna Terminal Resistance
Radiation Pattern	A plot of the electric field strength in polar coordinates.
Polarization	The direction of the electric field vector with respect to a set of coordinate axes.
Linear Polarization	The direction of the resultant electric field vector is constant with time.
Vertical Polarization	Resultant electric vector is perpendicular to the earth surface for the antenna orientation.
Radiation Intensity	The power radiated by an antenna per unit solid angle in a particular direction.
Gain	Ratio of maximum radiation intensity in a given direction to the maximum radiation intensity produced in the same direction by a hypothetical lossless antenna which radiates uniformly in all directions (an isotropic radiator) for the same power input.

ACKNOWLEDGEMENTS

I wish to thank the many personnel at the Division Communications Office at Fort Ord Army Base, especially Major Schreibstein and Captain Goodard for cheerfully providing the necessary equipment needed in this study.

My special thanks and sincerest appreciation is extended to Dr. Richard W. Adler, of BDM Corporation, to whom I am indebted to for his guidance, technical expertise on the NEC program and quiet patience throughout this endeavor.

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I. INTRODUCTION

A. BACKGROUND

All that is necessary for an individual to become acutely aware of the rapid advances being made in modern military weaponry and technology, is to listen to their favorite newscast or read their chosen periodical. Weapon accuracy, to point targets, and the destructive capability of these weapons, has reached a point that consideration of "first round" elimination or neutralization of a designated target is no longer reserved for the research community but must be included in the formulation of policy for military tactics. To be effective, the fighting force of the future must be a dynamic adaptive combat organization. The Commander of this force must be able to make correct and timely decisions, that are reflections of a continuously changing combat environment. The command must in turn be able to respond to these directives in a timely manner, or this force will cease to be effective. This response is contingent on the ability of the force to be able to react rapidly.

The Mobile Command Concept (MCC) [1] formulated at Naval Oceans Systems Center (NOSC) directly addresses the realistic possibility of a tactical command operating in an intense and lethal enemy environment. The result of this study is, that to be effective and to survive, in order to successfully

complete all assigned missions, this command must be mobile. It cannot be hampered by unwieldy structures that house sophisticated command, control and fire direction equipment. Married to these large structures are sufficient numbers of directional antennas that, correlated with the command structures, result in an accurate assessment of the size, type and composition of the unit.

The use of distributed systems and the application of the rapidly expanding technology in this area, has been proposed as a solution to the dilemma faced by the commander who desires maximum information, without having to sacrifice strategic or tactical mobility [2]. It would therefore be possible, with a highly mobile infantry unit, to run the command from the back of the jeep or similar vehicle, with only one or two radio systems. The judicious use of camouflage and the inclusion of distributed system techniques, would allow the commander and his staff to be dispersed without suffering the loss of any tactical capabilities. Subsequently this unit would be effectively obscured against sight, sound and infrared from all directions, including the air.

Hinged upon this concept is a fluid, dynamic communications system, unspecified in time as to direction. Choices of the types of communication equipment to use are still being investigated. Once these alternatives have been considered, the present choice of an antenna system to use can

be narrowed down to only a few. Because of the mobile scenario envisioned, these antennas must be omnidirectional, where coverage in all directions is required for warning or intercept functions. It is therefore necessary that an analysis be conducted on the performance characteristics of the antennas presently in use. What effect the structures that these antennas are mounted on, have on the performance, must also be realized.

B. OBJECTIVES OF THE ANALYSIS

The objectives of this report were to investigate the performance parameters of two basic VHF antenna structures, the RC-292 ground plane antenna and the mobile radio system antenna referred to in this report as the MRC-109. The MRC-109 utilizes the antenna, AS-1729, mounted on a M-151 vechicle chassis. Thin-wire computer modeling techniques were used to calculate a solution of the current distributions on each of these models. From these distributions, the input impedance, the gain and the associated horizontal and vertical radiation patterns of the antenna were obtained. An investigation on the effects of lossy earth upon these antennas was also conducted.

C. METHOD OF ANALYSIS

1. Computational Complexities

There are a number of techniques that allow one to calculate the characteristics of an antenna. Except for very

basic antenna configurations, the classical approaches, such as using conventional geometric descriptions and infinitely long line charges, where the potential and fields can be exactly calculated, would result in a very complicated mathematical procedure for arbitrary configurations such as a jeep. Fortunately, there are computer techniques that use direct integration or summing techniques, to obtain satisfactory results in accuracy and usefulness. Two basic techniques can be used and their employment is dependent on the size of the structure and its shape, relative to a frequency range of interest.

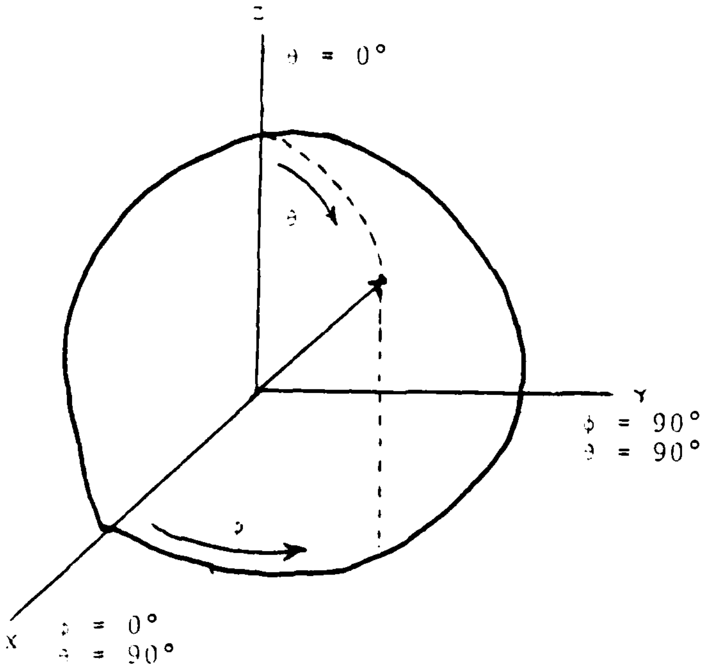
The first of these is the geometric theory of diffraction (GTD). The GTD method is used to determine the effects on the far field patterns, the gain of the antenna, due to obstacles and scatterers that surround the antenna at distances that are large relative to the wavelength. This is basically a ray optics technique, involving the reflection from surfaces and two basic diffraction mechanisms, edge diffraction and curved surface diffraction. When the wavelength increases (frequency decreases), or the size of the structure decreases, and/or the source of the energy becomes distributed, this technique no longer provides accurate answers. For the size of the antenna structures being analyzed, this technique is most appropriate in frequency ranges in excess of 500 MHz. However, since the frequency range that is of interest is between 30 and 75 MHz, the next technique was the one that was used.

The second technique, the method of moments (MOM), reduces the functional electromagnetic field equations to a set of equations that can be handled in a straight-forward fashion using the matrix manipulation on a digital computer [3]. This method is used for modeling the antenna and its immediate environment including nearby structures and antennas, up to a wavelength. This technique gives the impedance of the antenna and the current distributions on the antenna and nearby structures. From the current distribution and impedance, the gain and patterns may be found.

The method of moments technique used for this analysis was contained within the Numerical Electromagnetics Code (NEC). The NEC program was developed at Lawrence Livermore Laboratory for the Army, Navy and Air Force. It is based on previous antenna modeling programs, such as AMP, the Antenna Modeling Program. It employs MOM solutions and provides improved performance estimates of antennas mounted on ships, aircraft and spacecraft or on the earth's surface.

2. Geometrical Parameters

A spherical coordinate system was used throughout the calculations. For the antenna systems used, it was necessary to observe the patterns generated in the various spherical planes. An example of the system used is shown on the next page.



As an example, if the antenna under test was oriented along the z axis with a ground plane parallel to the xy plane, the azimuthal or horizontal angle of rotation, φ (phi), would be measured from the x axis in degrees. Similarily, the zenith or vertical angle, θ (theta), would be measured from the z axis downward toward the xy plane. A basic understanding of this is essential to an interpretation of the patterns obtained. A cross-sectional slice of the volume traced within the hemisphere will give a principle radiation lobe, which may not be symmetrical. Additionally, the secondary lobes can be observed.

5. Ground Influence

The antenna performance characteristics, especially the directive properties it exhibits, will be considerably influenced by the conditions of the earth beneath the antenna. This influence is proportional to the height of the antenna above it. A radiated field from an antenna is a result of the combination of the direct and reflected waves. The effect of the ground will be to alter the radiation intensity of the pattern for a particular vertical angle. The method of evaluating the impact of lossy earth on the patterns generated, which was used in this computer analysis, was the Fresnel's reflection coefficient approximation provided in the NEC program. This approach was used since the antenna elements, for both systems, were greater than .1 wavelengths above the surface of the earth. This method also conserved computer resources in time required for running the programs. A more exact method, the Sommerfeld / Norton method, is available in NEC however, this requires about 20 per cent more time to run. The Sommerfeld / Norton method was used for a sampling of computer runs for the RC-292. The results obtained were compared to similar runs using the Fresnel method. There was no appreciable difference between the two. Therefore, the estimated gains expected for this extra time were not substancial enough to warrant using Sommerfeld. The ground conditions evaluated were taken to represent what the antennas would be expected

to be operated over. The associated ground constants (epsilon and sigma) were obtained from the CCIR referenced and are listed below [4].

Ground Type	Dielectric Constant (epsilon)	Conductivity (sigma)
Wet Ground	30	.01
Pastoral	13	.005
Snow/Desert	3	.00012-.00018

It should be noted here that an analysis of the performance of the antenna systems over desert conditions was not considered necessary. The similarity of ground constants between snow and desert (epsilon=3 & sigma=.0001) made it impractical. Any of the results obtained for snow are felt to be applicable to desert conditions.

II. RC-292 ANTENNA SYSTEM

A. BACKGROUND

The RC-292 is an omnidirectional, VHF lightweight tactical communication antenna. It is presently used for broadcasting and net operations within the Marine Corps. This antenna is primarily used for medium range communications (3 - 20 km) with the individual transportable radio systems. As this antenna operates over a wide VHF frequency range (30 - 75 MHz) without any compensating coupling networks, it is necessary, as directed, that this structure be reconfigured each time it is used within one of three designated frequency ranges [5]. Each time that an operating frequency is assigned that transits from one range to another, it is necessary to disassemble and reassemble the antenna elements. Close monitoring of the antenna configuration is necessary when it is used in an environment of sequenced frequency changes. A mid-band constructed antenna, operating outside of this band, has been known to occur in a tactical environment [6].

B. OBJECTIVES

The objectives of this portion of the thesis were to correctly model the RC-292 antenna and to determine the related performance parameters and radiation patterns. If

this antenna is to be used in a distributed network system, in a tactical environment, it was necessary to learn:

(1) The directive and power gains for selected configurations of the antenna.

(2) The effect of constructing the antenna for the mid-band range and operating it through the entire range.

(3) The effects of selected finite ground conditions.

(4) The horizontal and vertical radiation patterns associated with each configuration.

(5) The effect of reducing the operating height.

C. SCOPE AND LIMITATIONS

The standard RC-292 as presently used has the following features:

(1) A mast mounted vertical monopole of variable segmented length (operating frequency dependent).

(2) A three element ground plane each of variable segmented length with 120 degrees separation. The ground plane is at an angle of approximately -56 degrees from the horizontal.

(3) A ceramic feedthrough insulator socket, MP-68, for mounting the antenna elements.

(4) Standard height above ground: 9.14 meters

(5) Operating bandwidth: 30 - 75.95 MHz

(6) Resonant frequency of operation for quarter wavelength:

Sub-Band I (30-36.5 MHz): 32.8 MHz

Sub-Band II (36.5-50.5 MHz): 43.18 MHz

Sub-Band III (50.5-75.95 MHz): 63.05 MHz

Details of this configuration are shown in Figures 1 and 2.

At the commencement of this study it was decided that some source of comparison was necessary to ensure close approximation of the computer model with the actual antenna. As no sufficiently accurate reports, with the necessary data, were known to be available, an actual antenna was obtained from personnel at Fort Ord Army Base.

There were few limitations placed on the development of this model, as this was a straightforward analysis of a basic tactical antenna. Where the analysis necessitated an assumption was in the determination of the characteristic impedance of the cables and radios used with this antenna. Both of these were assumed to have a characteristic impedance of 50 ohms. Mismatch losses were assumed not to occur between the cable and the radio. If any mismatch existed it was to be between the cable and the antenna. The differences in the transmission line losses between the ideal system modeled here and actual antenna were not considered.

The scope of this section includes:

(1) A comparison of the computer model and the actual.

(2) A comparison of the correctly configured antenna structure as detailed in the technical manual (TM configuration)

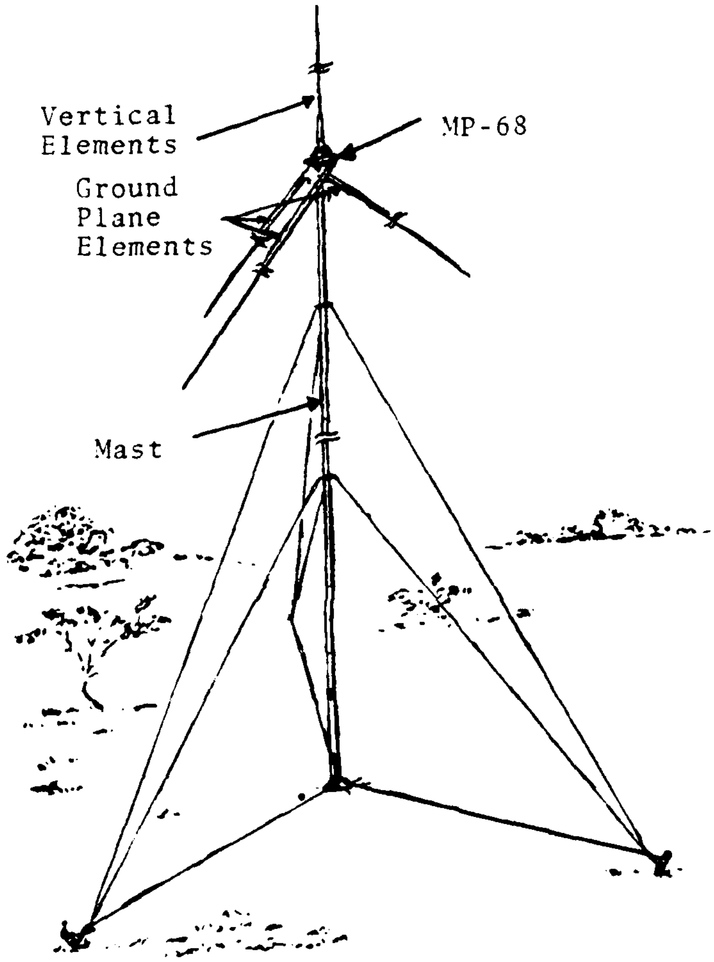
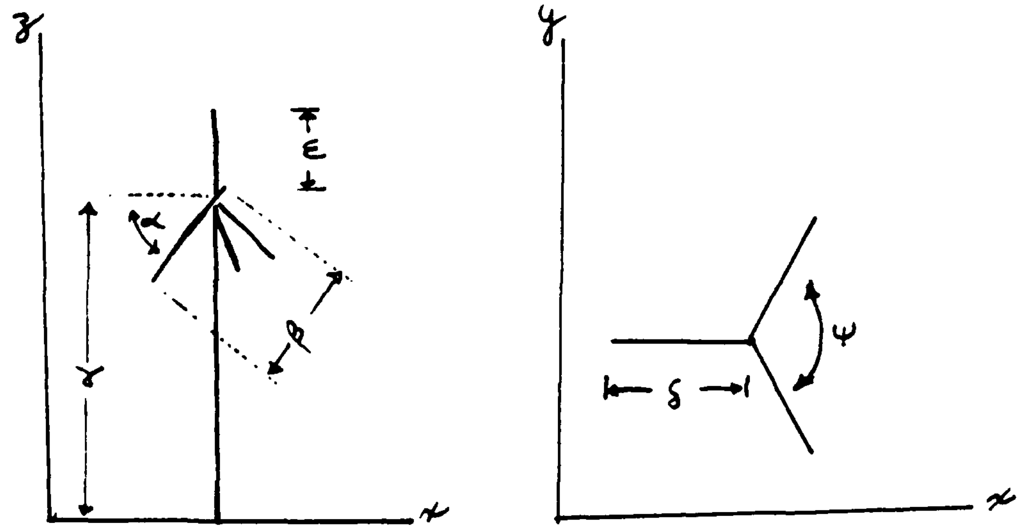


Figure 1 RC-292 Ground Plane Antenna



Sub-Band	I (30-36.5 MHz)	II (36.5-50.5 MHz)	III (50.5-75.95 MHz)
ψ	120°	120°	120°
α	-55.6°	-55.6°	-55.6°
β	2.67m	2.17m	1.67m
γ	9.15m	9.15m	9.15m
δ	1.51m	1.23m	.944m
ε	2.17m	1.65m	1.13m

Figure 2 Structural Geometry RC-292

with the mid-band (II) configured structure that is operated over the total operating range (Troop configured TC).

(3) A comparison of the directive and power gains of these two conflicting configurations TM vs TC, evaluating the root-mean-squared (rms) values of the gain for a bandwidth of 20 degrees the horizon (theta from 90 degrees to 70 degrees).

(4) An evaluation of the effects of lossy earth on the radiation patterns.

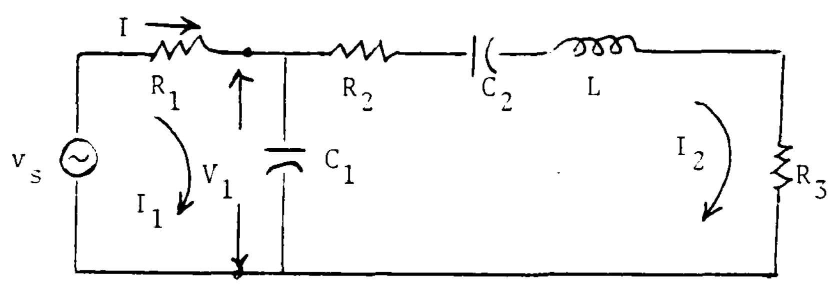
(5) A comparison of the radiation pattern of the technical manual configured at the height of 9.14 meters with a reduced height of 3 meters, over a nominal finite ground.

The structures were analyzed at four distinct frequencies in a wide frequency range, representing a small sampling of the complete system performance. A probabilistic total system analysis was not within the scope of this paper.

D. ANTENNA ANALYSIS

1. Mathematical Model of Antenna

The equivalent circuit of a short whip, monopole, antenna is shown below:



where: R_1 = source (generator) internal resistance

R_2 = effective series loss resistance due to I^2R loss in antenna conductor, ground return losses, and dielectric losses

R_3 = radiation resistance for vertical antenna

C_1 = base shunt capacitance

C_2 = effective antenna capacitance

L = antenna inductance

V_1 = rms voltage at base of antenna

In a half-wave or quarter-wave monopole operated at VHF frequencies the power lost as heat in the conductor (I^2 R2) does not exceed a few percent of the total power supplied to the antenna. The r.f. resistance of a copper conductor is very low compared to the radiation resistance of an antenna that is clear of surrounding objects and not close to the ground. Therefore, it was assumed that the ohmic loss, R_2, is negligible and that all of the resistance shown by the antenna is radiation resistance, R_3 = R rad.

To compute the radiated power (P rad) of the antenna, as a function of frequency, it was necessary to examine I_2 as

$$P\ rad = I_2^2 \times R\ rad$$

Consider two possibilities:

Case 1. The base shunt capacitance, C_1 is negligible. For this case I_2 is simply,

$$I_2 = (V_1) / (R_3 + jwL - (j/wC_2))$$

Noting that the antenna input impedance,

$$Zin = R_3 + jwL - (j/wC_2)$$

and defining antenna resonant frequency as

$$wr = 1 / (\sqrt{LC_2})$$

results in an input impedance of

$$Zin = w\ C_2\ R_3 + j((w/wr)^2 - 1)$$

Noting that at resonance, w = wr

$$Zin = w\ C_2\ R_3 \text{ (purely resistive)}$$

and the radiated power is

$$P\ rad = (V_1 / Zin)^2 \times R\ rad$$

Case 2. The base shunt capacitance is significant and influences the antenna performance.

$$Zin = (-j/wC_1) // (R_3 + jwL - (j/wC_2))$$

$$Zin = [((w/wr)^2-1)-jw^2C_1C_2R_3] / [wC_2R_3-j((w/wr)^2-1+wC_1)]$$

which shows even at resonance, w = wr

$$Zin - (-jw^2C_1C_2R_3) / (wC_2R_3-jwC_1)$$

capacitive loading will result. Total available radiated power will decrease as a result of decreased I_2, proportional to the increase of I_1, ($I_2 = I - I_1$). The value of I_1 is dependent on the value of C_1 and the operational frequency. For a large value of shunt capacitance the antenna system will not be resonant.

It should be emphasized that it is not easy to determine the values of the elements of the equivalent circuit of the monopole, even with accurate feed-point impedance (Zin) data. These depend on variable parameters, as antenna height, frequency of interest and the dimensional quantities of the structure (length to diameter ratio). Even if a perfectly matched resonant antenna was used to determine the radiated power from a given input power, so that the antenna efficiency would be known, it still would be necessary to make an estimate of the directivity of the antenna, to determine the power gain for a particular zenith angle. It is therefore necessary, faced with the difficulties of theoretical computations, to devise a data analysis technique that would couple empirical and numerical approaches.

2. Actual Antenna Testing

There is no compensating coupling or matching unit associated with the RC-292 antenna, therefore it was necessary to determine the input impedance of the antenna system. A precise method of measurement consists of calculating the electric and magnetic fields at all points of

the antenna and then integrating these. It is then possible to know the real power and the reactive power at each point and by integration, the total resistance and reactance can be obtained. These calculations are quite complicated and must be made for variable frequencies. To remedy this problem an empirical solution was invoked.

To be able to use results from any developed computer model with some certainty that these reflected the actual operating characteristics of the antenna, an acutal antenna was tested. The test facilities at this school were used with an antenna obtained from Fort Ord.

The measurement principle was very straightforward. The equipment was set up as shown in Figure 3. The reflectometer was used to derive samples of the incident and reflected waves, V+ and V-, and these were then processed by the vector voltmeter. This displayed the rms values of the A and B channel voltages and the phase of Vb with respect to Va. Thus the load reflection coefficient was easily calculated as,

$$§ = Vb / Va < \phi$$

and the load (input) impedance was then found from the relation,

$$Zin = Zo \times [1+§)/(1-§)]$$

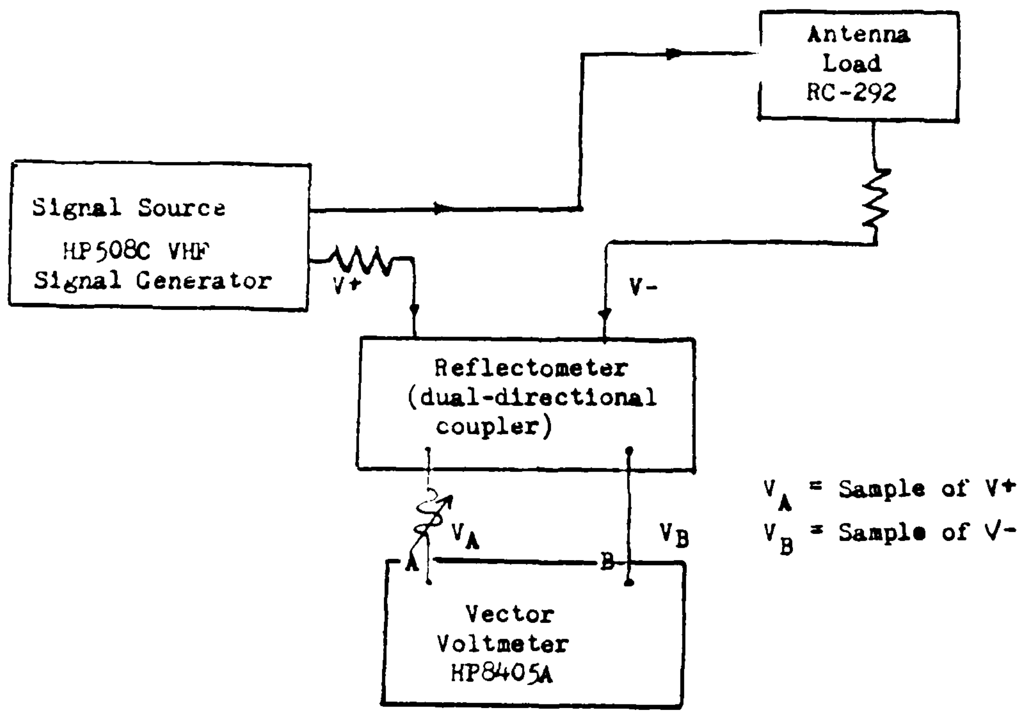


Figure 3 Antenna Impedance Measurement

where Zo is the characteristic impedance of the line. The adjustable reference line was present to compensate for the difference in path length for the samples of V+ and V-.

The dimensional configurations used were the same as shown in Figure 2. The variable parameter considered was the frequency. This dictated when an antenna configuration would be changed, e.g. when the frequency tested changed from 35 MHz to 40 MHz, the structure was changed to conform with the guidance in the technical manual. This was done except in the case when the "Troop" configuration was tested. This "field version" antenna was constructed for sub-band II and operated from sub-band I through sub-band III. Both configurations, tech manual TM and troop TC, were tested with the actual data recorded, shown in Figures 4 and 5. The results of the data indicated that a value of capacitive reactance was acting upon the system, preventing the antenna from attaining a resonant value (pure resistance). From the mathematical analysis previously presented, the indication was a problem existed with an inordinate amount of input shunt capacitance. Further measurements were taken after totally disassembling the antenna, leaving simply the antenna support and the antenna base, MP-68. As shown in Figure 6, the MP-68 has a ceramic insulator as a structural support, separating the antenna vertical feedpoint with the ground plane support. It was calculated, using the below table of results,

TECH MANUAL CONFIG

freq (MHz)	sub band	angle	reflec ρ	R	X	Zin
				(Z_o = 50 ohms)		
30	I	-70	.24	1.05	-0.50	52.5-j25
35	I	-13	.58	3.00	-1.40	150-j70
40	I	-42	.21	1.30	-0.4	66.0-j20
45	II	-7	.54	3.20	-0.6	160-j30
50	II	-26	.72	2.20	-2.8	110-j140
55	III	-70	.15	1.08	-0.32	54.0-j16
60	III	-30	.47	1.9	-1.05	95-j52.5
65	III	-44	.62	1.3	-1.7	65-j85
70	III	-51	.69	.88	-1.78	44-j89
75	III	-60	.75	.53	-1.6	26.5-j80

Figure 4 Actual Tested Antenna Input Impedances: Technical Manual Configuration

TROOPCONFIG

freq (MHz)	sub band	angle	reflec ρ	R (Z_o=50 ohms)	X	Zin
30	II	-40	1	0	-2.7	0-j135
35	II	-70	.72	.48	-1.32	24-j66
40	II	-42	.21	1.3	-.4	66-j20
45	II	-7	.54	3.2	-.6	160-j30
50	II	-26	.72	2.2	-2.8	110-j140
55	II	-34	.8	1.2	-2.82	60-j141
60	II	-28	.83	1.4	-3.45	70-j173
65	II	-40	.8	.9	-2.45	45-j123
70	II	-48	.8	.68	-2.1	34-j105
75	II	-54	.98	.1	-1.98	5-j100

Figure 5 Actual Tested Antenna Input Impedances: Troop Configuration

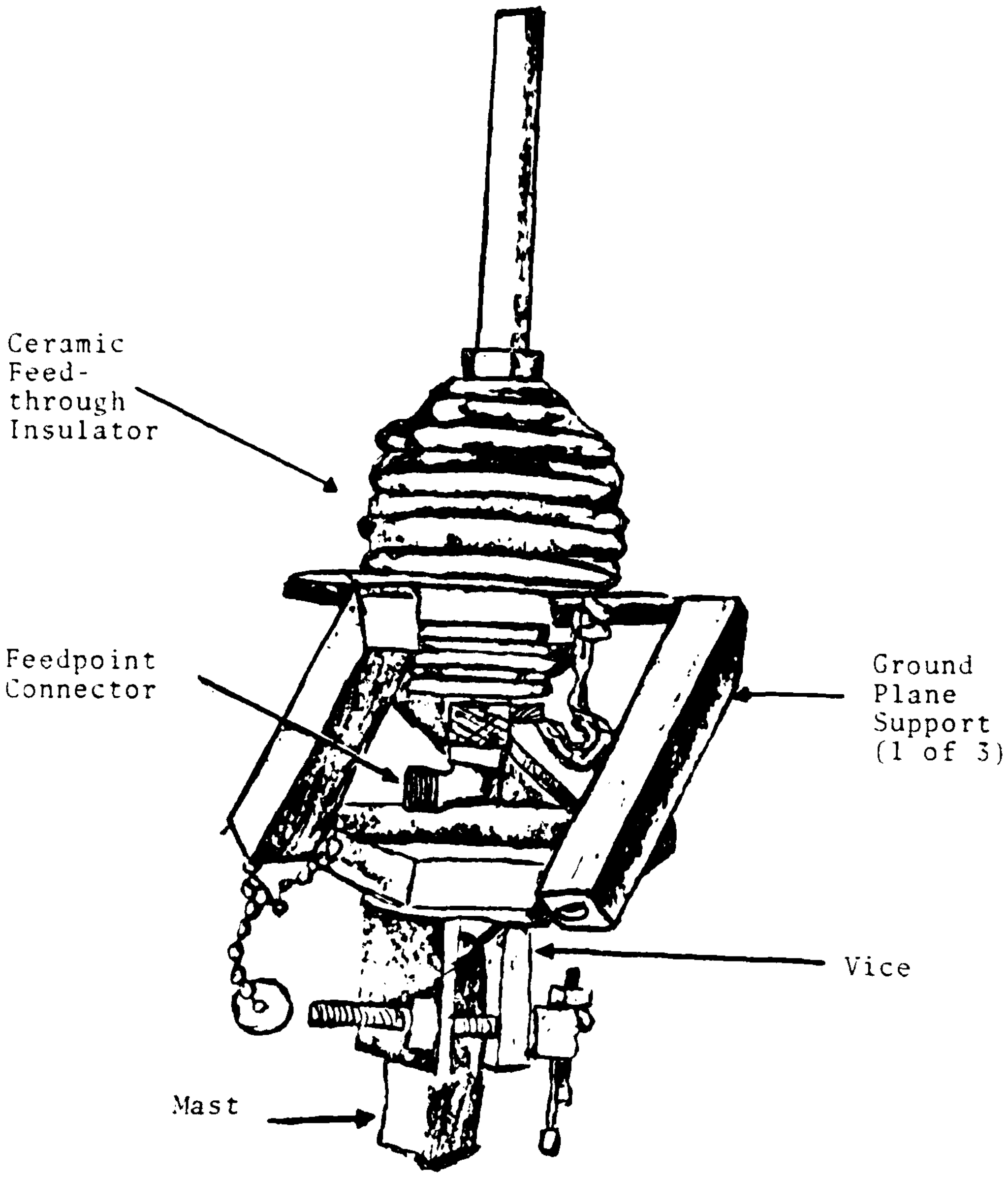


Figure 6 Antenna Base, MP-68

freq (Mhz)	reflection angle	Xc'	Xc (ohms)	Capacitance (pfd)
75	-64	-j1.6	80	26.5
50	-49	-j2.2	110	28.9
30	-31	-j3.6	180	29.4
20	-19.5	-j6	300	26.5
10	-8.5	-j13	650	24.48

that the antenna base was adding approximately 27pfd of capacitance to the antenna feedpoint. This was the same situation, which has been shown in the mathematical analysis, resulted in a non-resonant antenna. This was indeed the case in the RC-292. The MP-68 was preventing the recommended configuration as outlined in the technical manual, from being resonant.

With the physical and impedance characteristics determined, it was now possible to construct the computer NEC model and compare the results.

3. Computer Model Development

The important design considerations that were necessary to follow in this computer model development were the antenna segmentation size, the radius of the segments and the proper geometrical model. For wire modeling of the antenna, the main electrical consideration is segment length

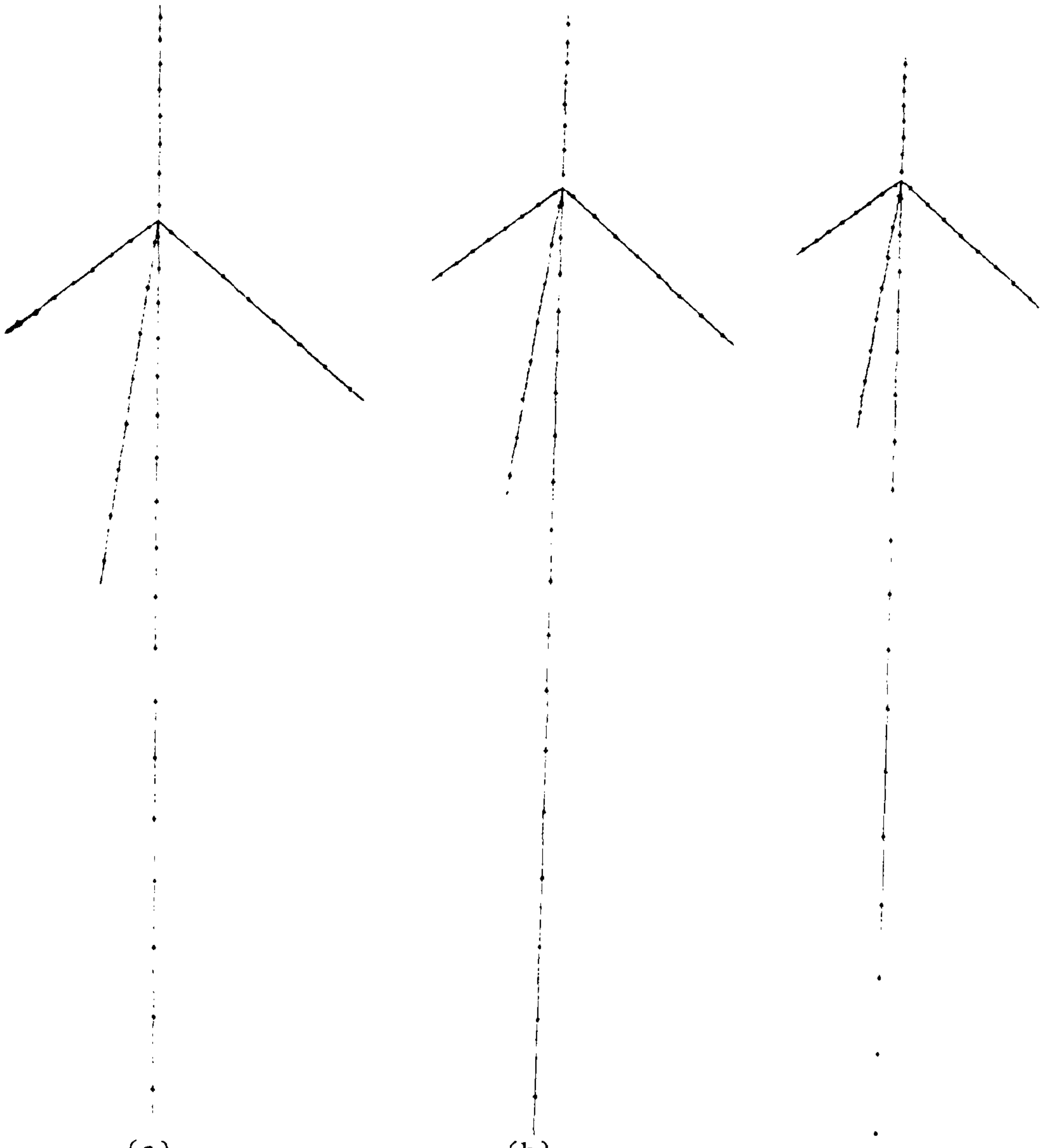
(delta) relative to the wavelength (lambda λ) [7]. For accurate results, delta should be less than approximately .1 lambda at the desired frequency. The wire radius, "a", relative to the wavelength, is limited to the approximation, that the relationship of,

$$((2\ \pi\ a)/\text{lambda}) \ll 1$$

must hold for the antenna configuration. Using these guidelines, the antenna was modeled at a reference frequency of 75 MHz as shown in Figure 7, with the three antenna configurations shown. The segmentation used is illustrated by the small arrows. A sample of the geometry structure data used to create these models can be located in Appendix C.

4. <u>NEC Computer Model vs. the Actual</u>

A comparative data analysis was done between the NEC model and the physical antenna. The input impedances that were obtained from the NEC program calculations and the input impedances that were obtained through the actual tests on the antenna were plotted on Smith charts. The MP-68 input loading of 27 pfd was added to the computer model. Plots of the impedance loci are shown in Figures 8 through 11. From the comparison of these plots, it was clear that an acceptably accurate model for each individual configuration existed.



(a)
Sub-band I
30-36.5 MHz

(b)
Sub-band II
36.5-50.5 MHz
(Troop)

(c)
Sub-band III
50.5-75.95 MHz

Figure 7 NEC Models For RC-292

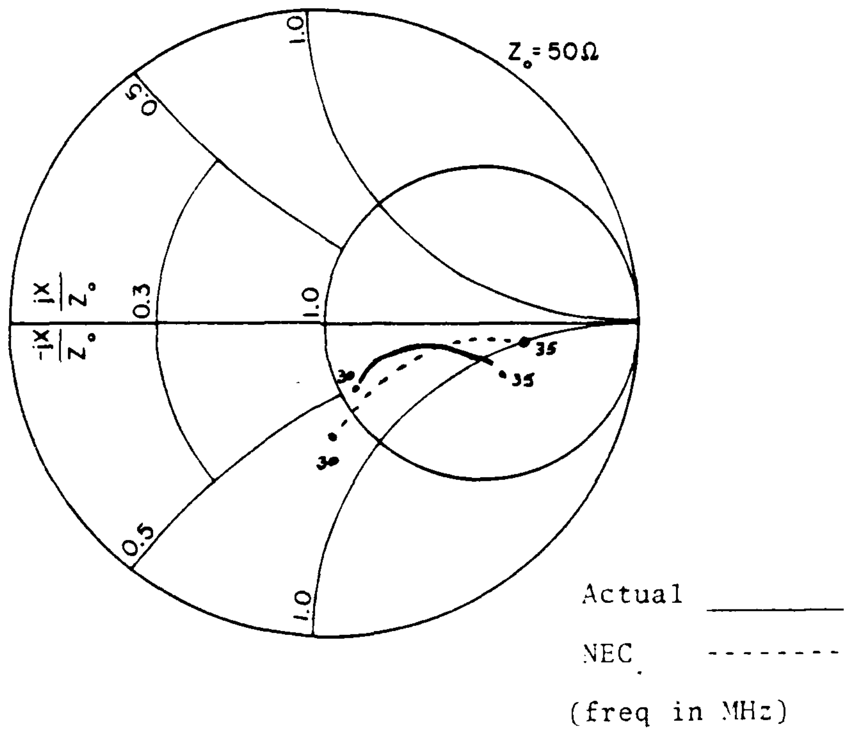
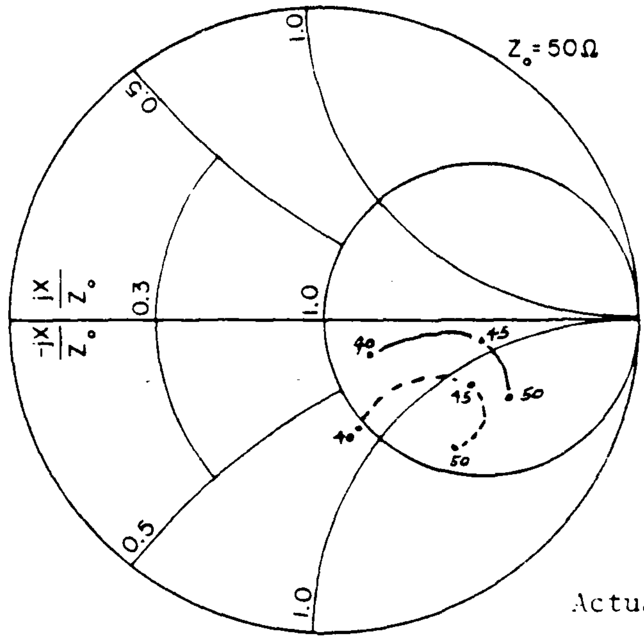


Figure 8 Comparison of Impedance Coordinates for Technical Manual Configuration: Sub-band I



Actual ________

NEC - - - - - - -

(freq in MHz)

Figure 9 Comparison of Impedance Coordinates for Technical Manual Configuration Sub-band II

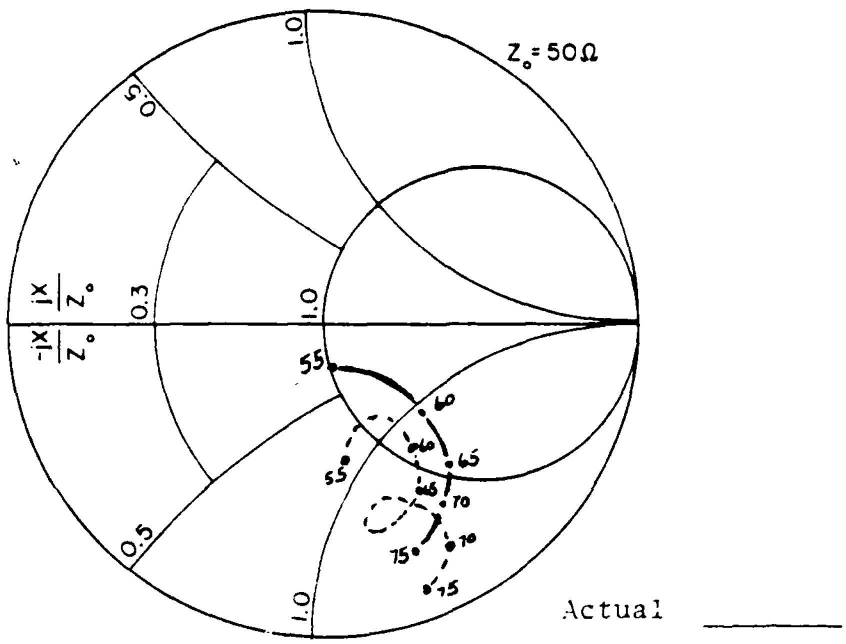


Figure 10 Comparison of Impedance Coordinates for Technical Manual Configuration Sub-band III

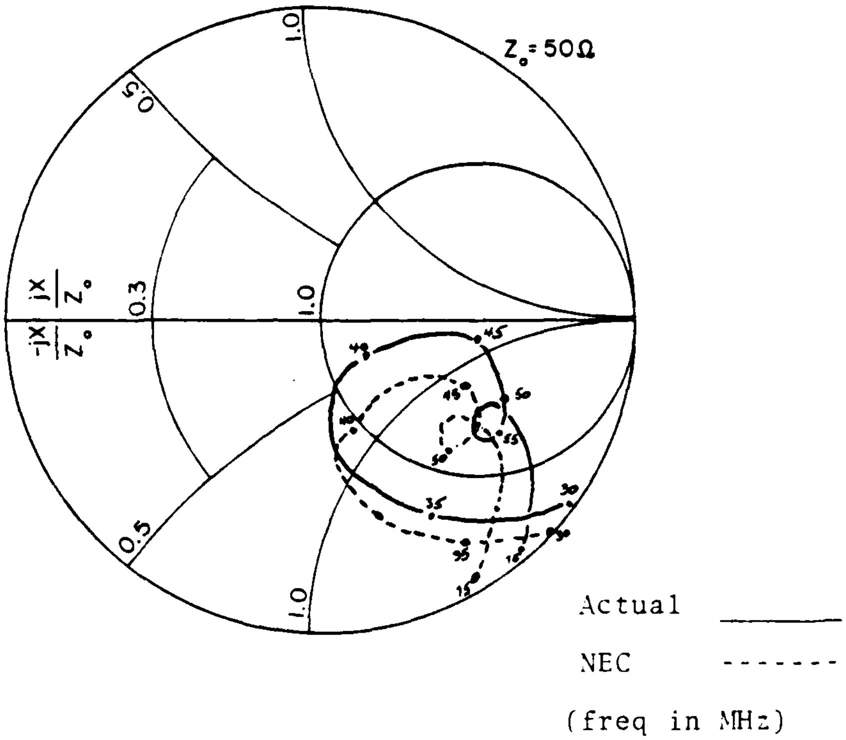


Figure 11 Comparison of Impedance Coordinates for Troop Configuration (30-75 MHz)

E. RC-292 ANTENNA PERFORMANCE CHARACTERISTICS

Antennas have such unusual current distributions and complex fields that field characteristics are usually expressed in terms of performance relative to a hypothetical isotropic radiator which produces the same radiation intensity in all directions. This "measuring stick" was used throughout the remainder of this thesis for comparing the properties of the antenna system. These properties were:

(1) Directive gain comparison between the technical manual and the troop configurations.

(2) Power gain comparison of these configurations where the structures are positioned over perfect and lossy ground.

(3) Comparison of the radiation patterns, both horizontal and vertical, generated by these configurations.

(4) Effect on the gain and patterns when the height of the antenna was reduced from 9.14 meters to 3 meters.

1. Directive Gain.

The directive gain of an antenna is a measure of the field strength of power density for a given directional area. That area of interest for this analysis was from the horizon to an increased elevation angle of 20 degrees. The directive gain calculations neglect any losses in the structure from mismatch. A plot of the average directive gain resulting from the model calculations is shown in Figure 12. As can be readily seen without consideration of mismatch losses, there appears to be very little difference between the two

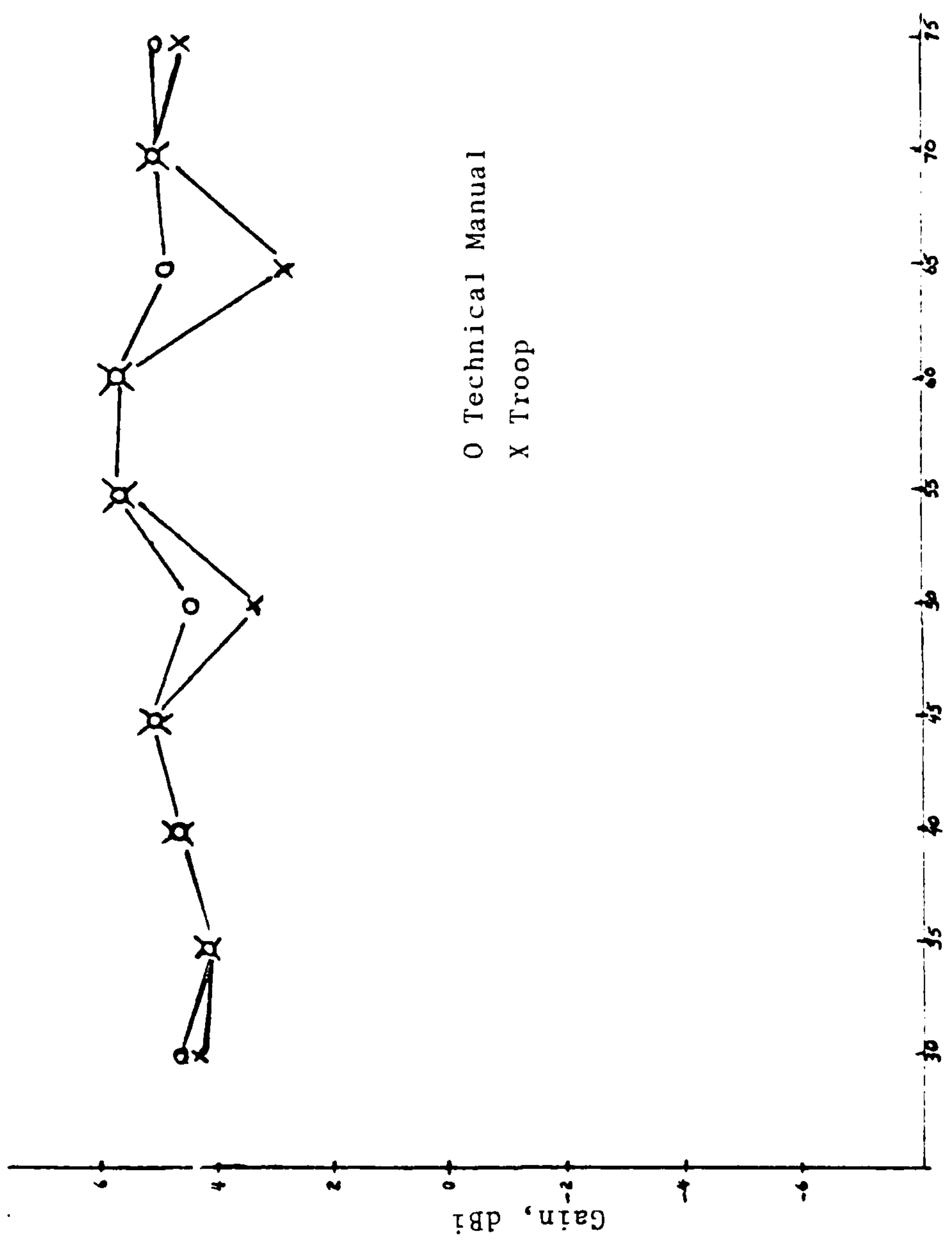


Figure 12 Average Directive Gain: Perfect Ground

configurations. This was expected considering the similarity of function, monopole radiators.

2. <u>Power Gain</u>

The power gain of an antenna is a similar measure of the field strength for a given directional area but this calculation takes into account the efficiency of the particular antenna. These calculations consider the loading and mismatch losses associated with the antenna structure. As Figure 13 illustrated, there was an appreciable difference between the two configurations. These calculations indicated there was as great as 10 dB difference between the TM and TC configurations for the low range of operation. There was no difference, as would be expected, in the mid-range, since this is the designed range of operation for this particular configuration. Figures 14 through 16 illustrate these differences in average power gain over the area of interest, 20 degree bandwidth. The particular configurations were analyzed above the three ground conditions. The height of the antennas when calculations were made was set at the normal operating height, 9.14 meters. The results indicated that there existed very small differences, 1 dB, for the technical manual configuration for the ground considered. An average overall power gain of approximately 2 dB resulted for this configuration. The "troop configuration" varied approximately 2 dB between the ground conditions. However, the average overall power gain was -5 dB.

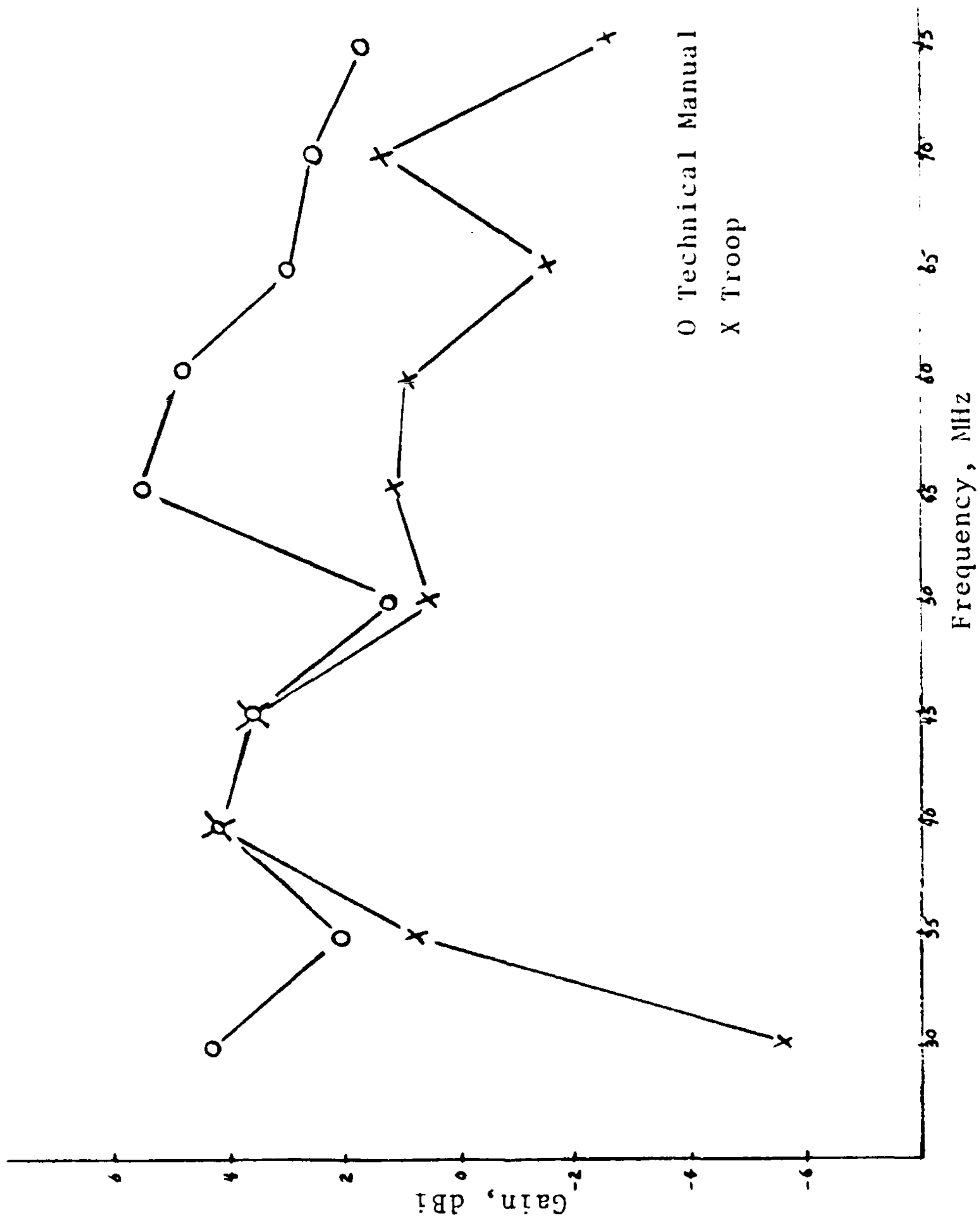


Figure 13 Average Power Gain: Perfect Ground

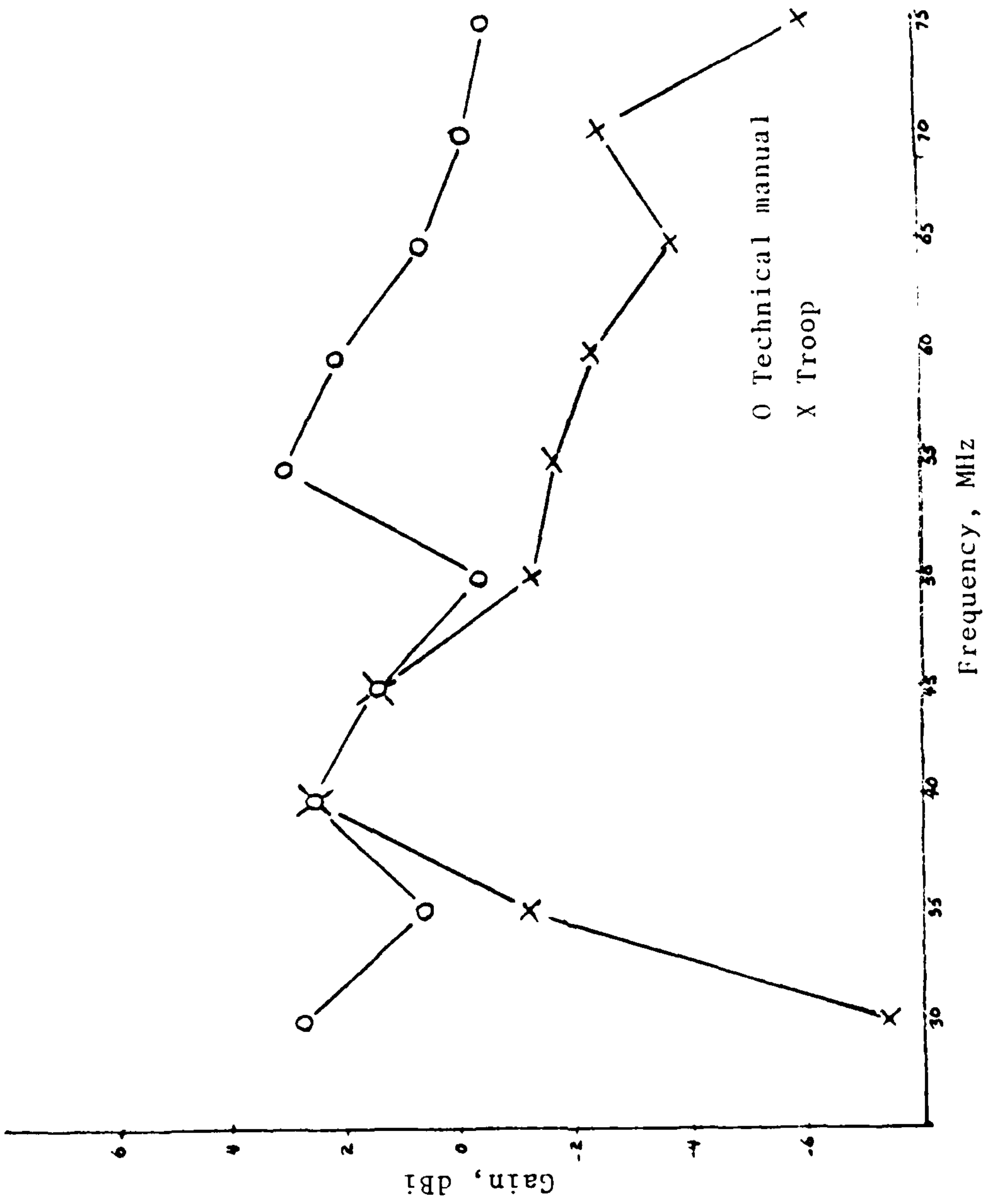


Figure 14 Average Power Gain: Snow

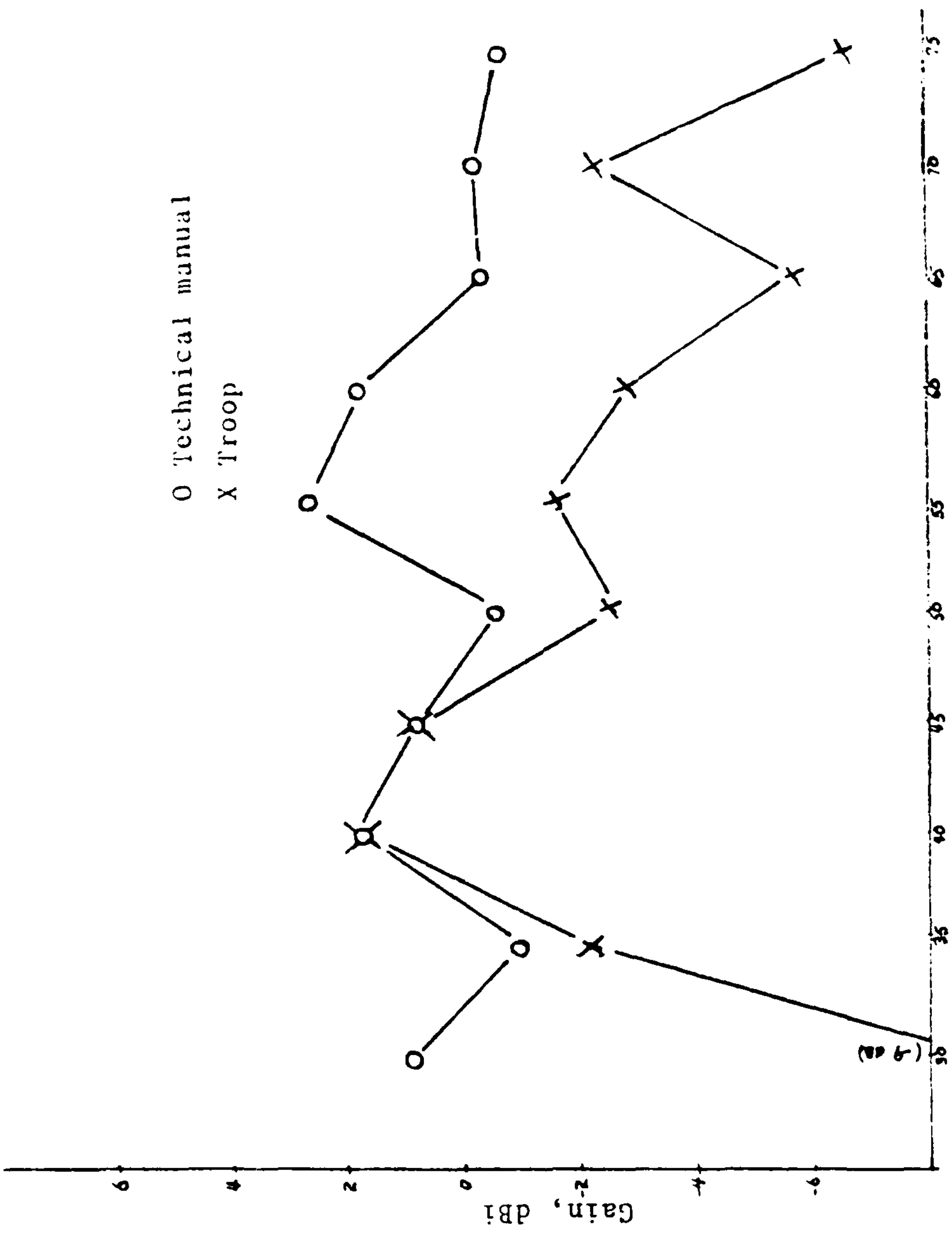


Figure 15 Average Power Gain: Pastoral

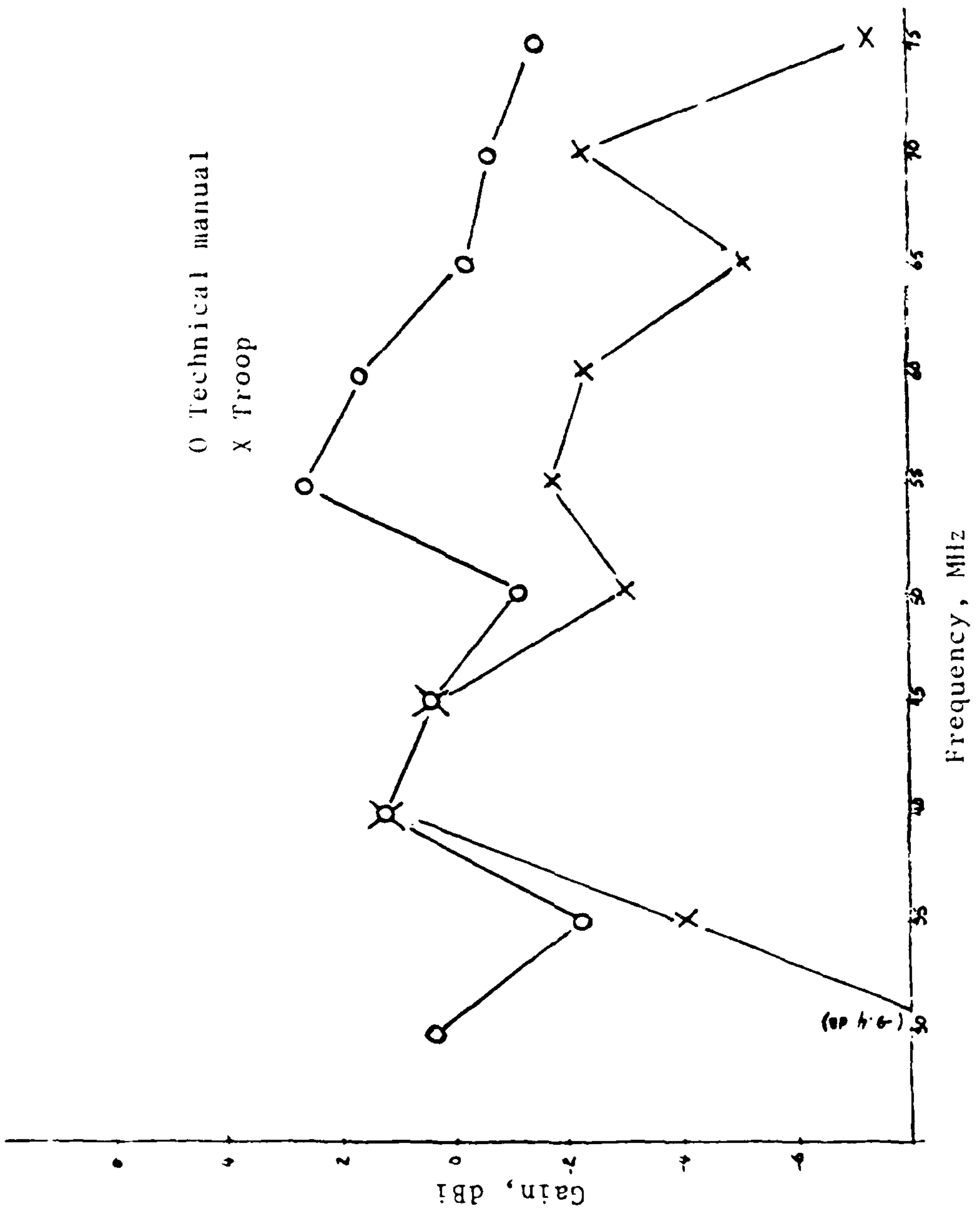


Figure 16 Average Power Gain: Wet Ground

3. Radiation Patterns

Appendix A contains a complete set of the radiation patterns generated for the conditions analyzed in this study. It was determined from the radiation patterns generated, as a result of the computer runs, that the RC-292 was indeed an omnidirectional radiator. An example of one of the horizontal patterns generated within this "look area" is shown in Figure 17. With an omnidirectional antenna, symmetry with the vertical pattern would be expected. To verify this, patterns were generated. In the development of the computer model, a ground element was oriented along the y axis (ϕ = 90deg) and the other two ground elements were spaced 120 degrees apart (ϕ = 210deg and 330deg). A comparison of the vertical patterns, where a ground element was present, ϕ = 90deg, and where there was not, ϕ = 180deg, pointed out that the RC-292 radiation patterns appeared to be quite symmetrical in the vertical plane. This is shown in comparing Figures 18 and 19. Therefore, only one vertical "cut" has been included in the Appendix for each parameter analyzed.

A vertical radiation pattern for the "troop" configuration is shown in Figure 20. The power gain losses associated between "troop" configuration and the technical manual configuration at the low range of operation can be readily extracted from comparing Figures 20 and 18. Here

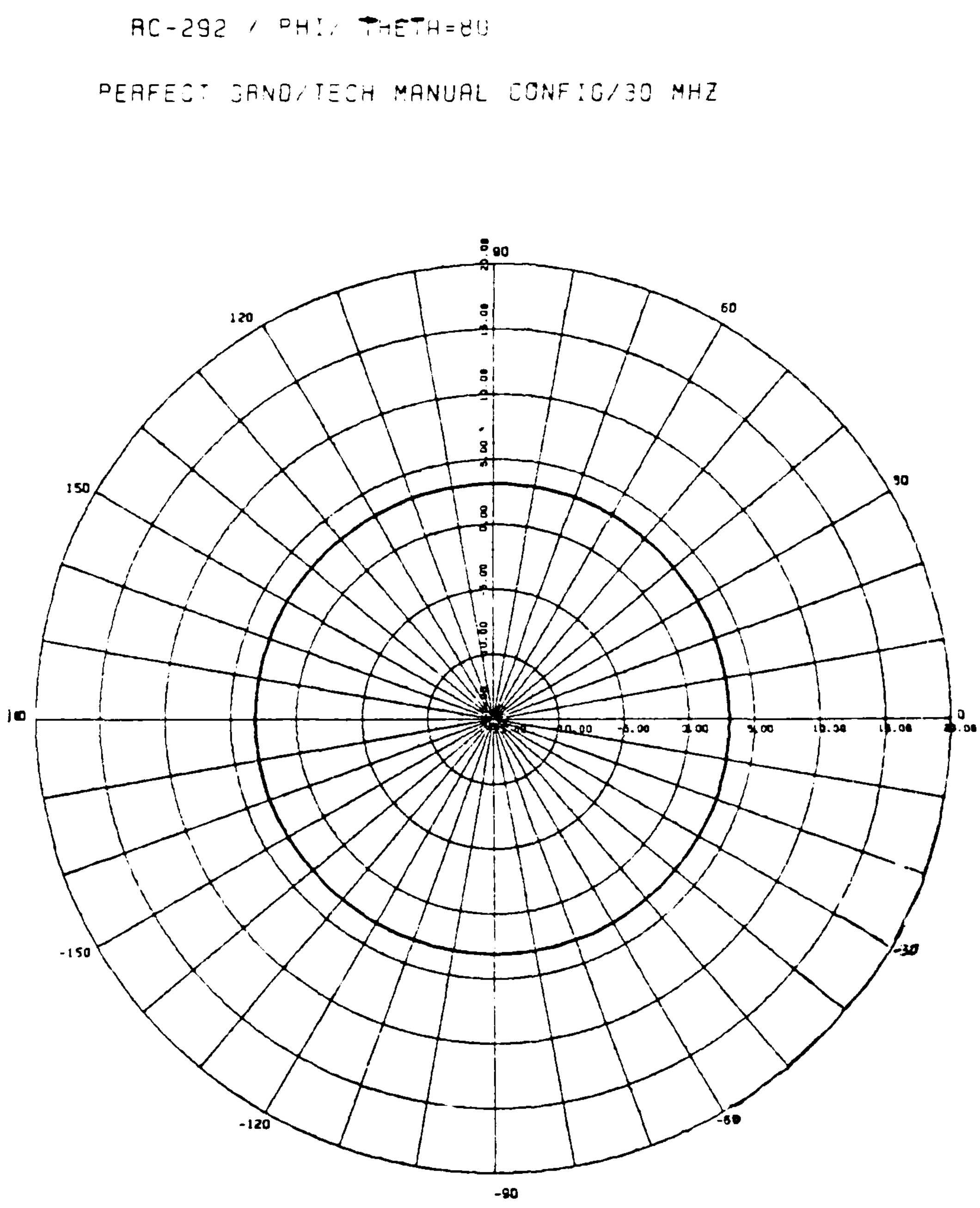


Figure 17 Horizontal Radiation Pattern:
10 Degrees From Horizon

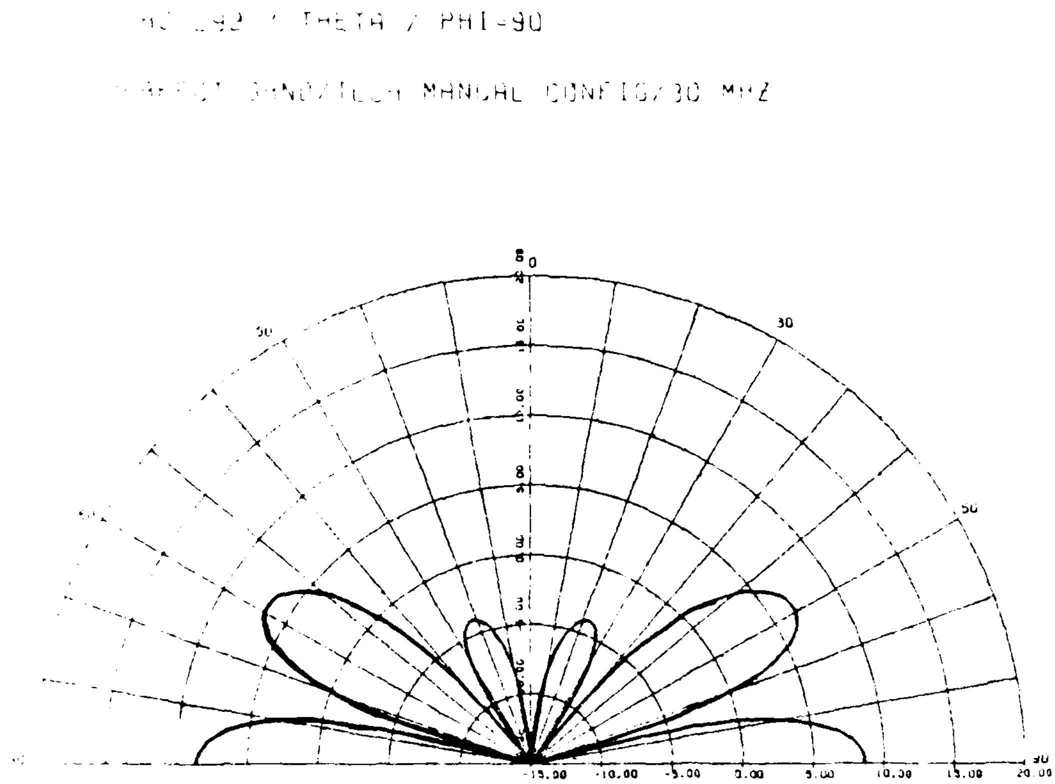


Figure 18 Vertical Radiation Pattern (TM)
In Plane Of Ground Element

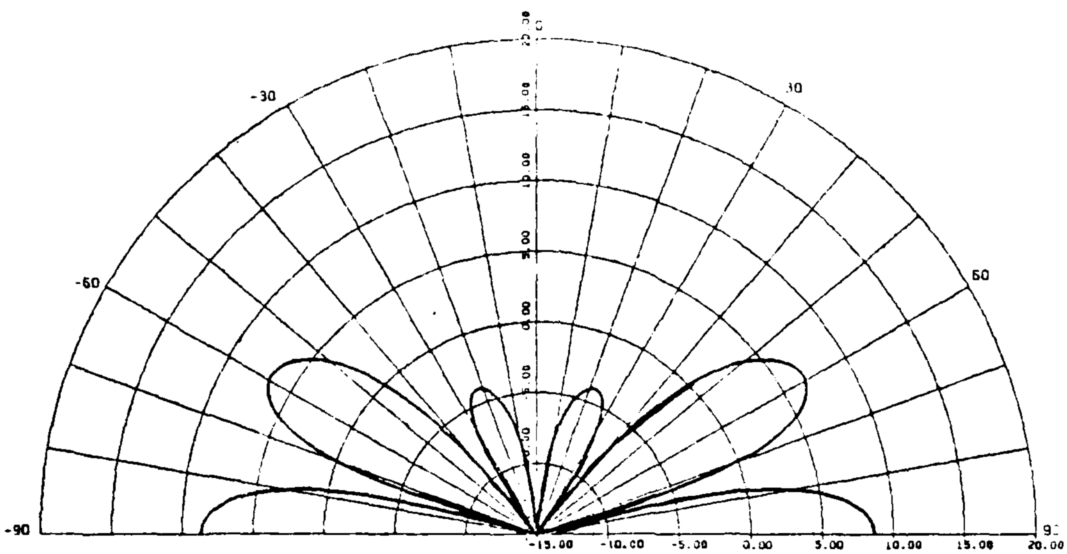


Figure 19 Vertical Radiation Pattern (TM)
In Plane With No Ground Element

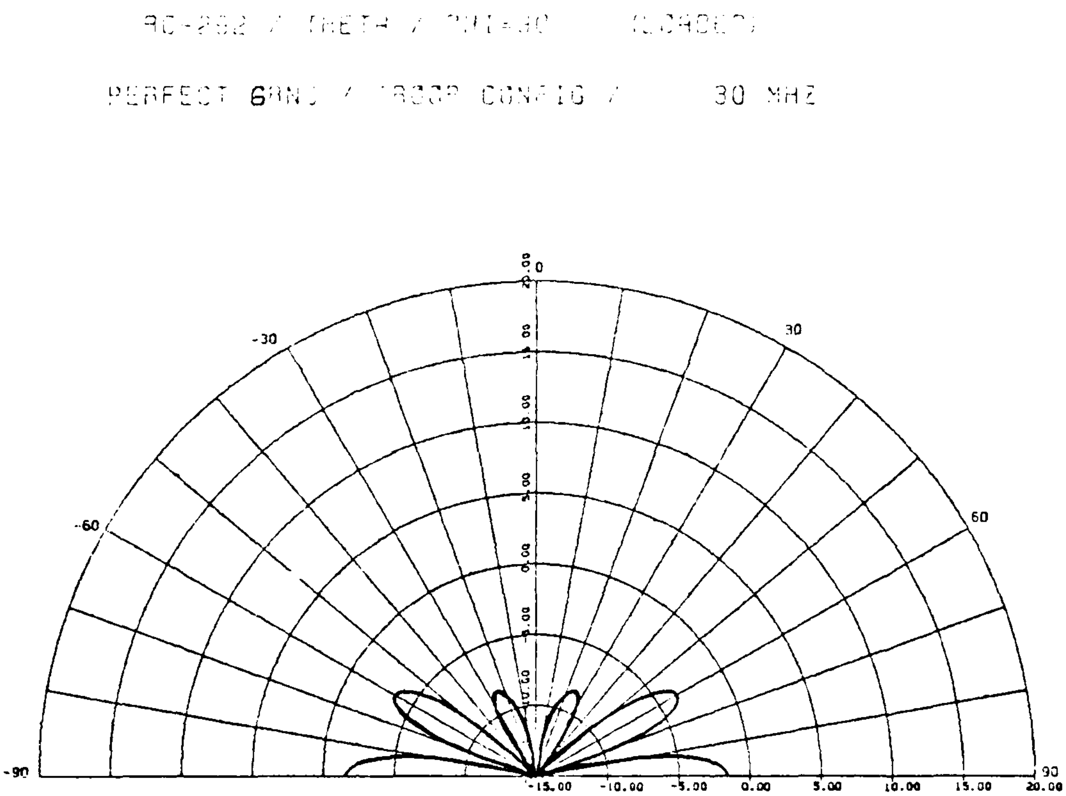
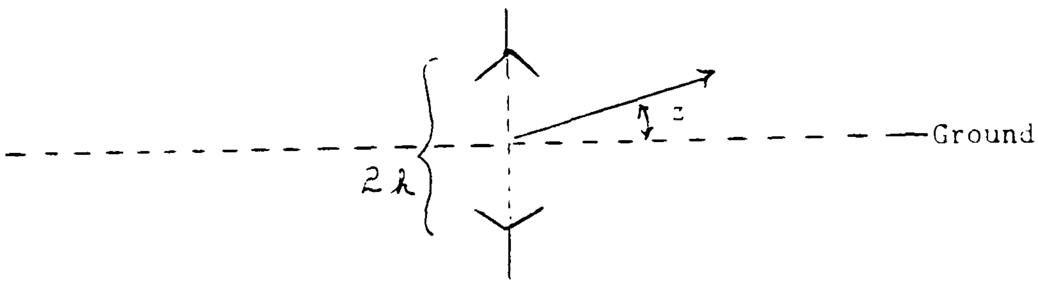


Figure 20 Vertical Radiation Pattern For Troop
Configuration: Perfect Ground

at 30 MHz, the power gain differential was 10 dB between configurations.

4. <u>Height Variations</u>

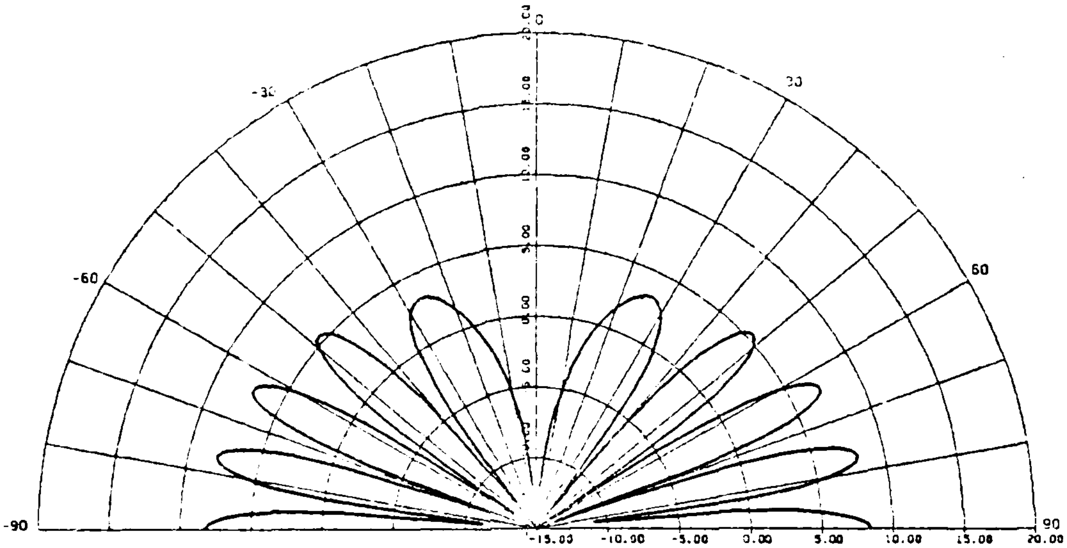
An examination of Figure 21 showed "lobing" of the pattern when the antenna was operated at 75 MHz for the normal height of 9.14 meters. The number of lobes can be directly attributed to the height of the structure above the ground and the frequency of operation. The principle of images can be applied to a vertical antenna in the presence of earth as shown below.



The amplitude of a vertical antenna's radiated pattern is proportional to:

$$f(z) = 2\cos \left[\left((2\pi h)/\text{lamba} \right) \sin z \right]$$

From this relationship, it was noticed that as the height of the antenna was decreased, or the separation of the antenna from its image was decreased, then the radiation pattern diagrams would consist of progressivley smaller numbers of lobes. A comparison of Figures 21 and 22 illustrated that this was indeed the case. As the antenna operational height



Directive Gain: dBi

Figure 21 Vertical Radiation Pattern (TM) Antenna
Height: 9.14 meters, freq: 75 MHz

RC-292 / THETA / PHI=90

PER GRND / TM CONFIG HEIGHT=3M / 75 MHZ

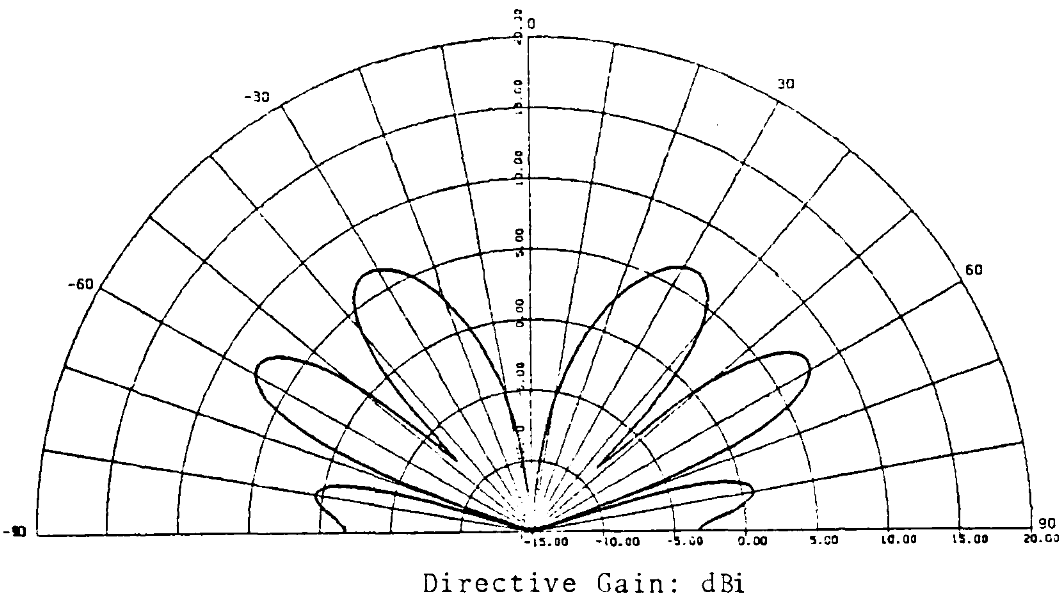


Figure 22 Vertical Radiation Pattern (TM) Antenna
Height: 3 Meters, freq: 75 MHz

was decreased from 9.14 meters to 3 meters, the number of lobes per octant decreased from 4.5 to 2. Included in Appendix A was a set of patterns generated when the antenna was operated over snow at a elevation of 3 meters. A reduction in operational height for the TM configuration over lossy earth resulted in a decrease in power gain of approximately 3 dB. Additionally an increase in the angle of maximum radiation of 10 degrees, from 10 degrees above the horizon to 20 degrees above the horizon, resulted.

Contained in Appendix A are sets of directive and power gain radiation patterns for the azimuth plane 10 degrees above the horizon. Vertical patterns for the elevation plane at an azimuthal angle of 90 degrees has also been included. Each set constitutes a sampling of variable parameters for frequency, ground conditions and height. The estimated gain from these, for some parameter of interest, height, frequency, configuration, can be rapidly realized.

F. OUTLINE OF RESULTS

The results of the analysis indicated that:

(1) The RC-292 was a symmetrical, omnidirectional antenna.

(2) The mechanical or structural support for the antenna element, the MP-68, inhibits the performance of the correctly configured antenna (tech manual) by a factor of from 0 to 3 dB.

(3) A mid-band designed antenna operated outside its correct range of construction, "troop", resulted in an appreciably worse performance, -10 dB. This configuration should not be considered in any distributed system network.

(4) The ground beneath the antenna produced a variance from 1 to 3 dB loss, from ideal, for a given directivity.

(5) The height of the antenna did effect the radiation pattern where the recommended operating height was 9.14 meters.

Additionally, replacement of the ceramic material for the MP-68 with another dielectric material would have to be carefully studied. The ceramic material for the MP-68 has the following attractive insulating properties: [8]

(1) high mechanical strength (when properly used)

(2) high weathering and corrision resistance

(3) low permeability to gases and vapors

(4) excellent temperature stability

(5) low dielectric loss

(6) high dimensional stability

Other insulating materials that may be considered to replace the ceramic bowl in the MP-68 may not possess these same weathering characteristics. Based on the findings in this study and the effect the input shunt capacitance has on the antenna performance, close scrutiny of replacement materials is recommended.

III. MRC-109 VEHICLE MOUNTED ANTENNA

A. BACKGROUND

A relatively light-weight tactical vehicle configured radio system is one of the most important elements in a rapid mobile communications scenario. Light-weight and tactical implies that this system must be capable of being air lifted, helo lifted, sea lifted, driven or parachuted into any possible terrain condition and upon arrival functioning immediately for the Commander.

An understanding of the operational parameters of the antenna that is used with this communication system is essential for ensuring constant reliable information exchange. The effects of the antenna positioning on the vehicle, of the vehicle structure, and of the ground beneath the vehicle, have upon the pattern generated require to be realized. The degree of antenna pattern degradation that can be tolerated, depends largely on the characteristics of the system to which the antenna is connected. If the system functions by detecting nulls in the antenna pattern at some azimuth and zenith angle, the antenna null position and depth, hence the performance, may be a critical function of the antenna. For a distributed network system, it is desireable that the antenna radiate and receive equally well in all directions. Pattern degradation will definitely decrease the effectiveness of this system.

B. OBJECTIVES

The objectives of this portion of the thesis were to correctly design a computer model for a vehicular configured VHF antenna system and to determine its related radiation patterns. The particular configuration that was modeled and is referred to throughout this section, and the associated appendix, was the MRC-109. This configuration consisted of a vertically polarized monopole antenna, the AS-1729, mounted on a M-151 jeep chassis as shown in Figure 23. To use this configuration in a distributed communication system, it was necessary to learn:

(1) In what manner a particularly configured vehicle affects the radiation pattern.

(2) The effects of dissipative earth on the patterns generated.

(3) Thin-wire approximation modeling effects.

C. SCOPE AND LIMITATIONS

Three possible jeep configurations were modeled, having the following features:

(1) The "Basic" configuration was the vehicle chassis modeled without having the windshield or canvas cover brace employed.

(2) The "Jeep" configuration was the vehicle chassis modeled with both the windshield and canvas cover brace employed.

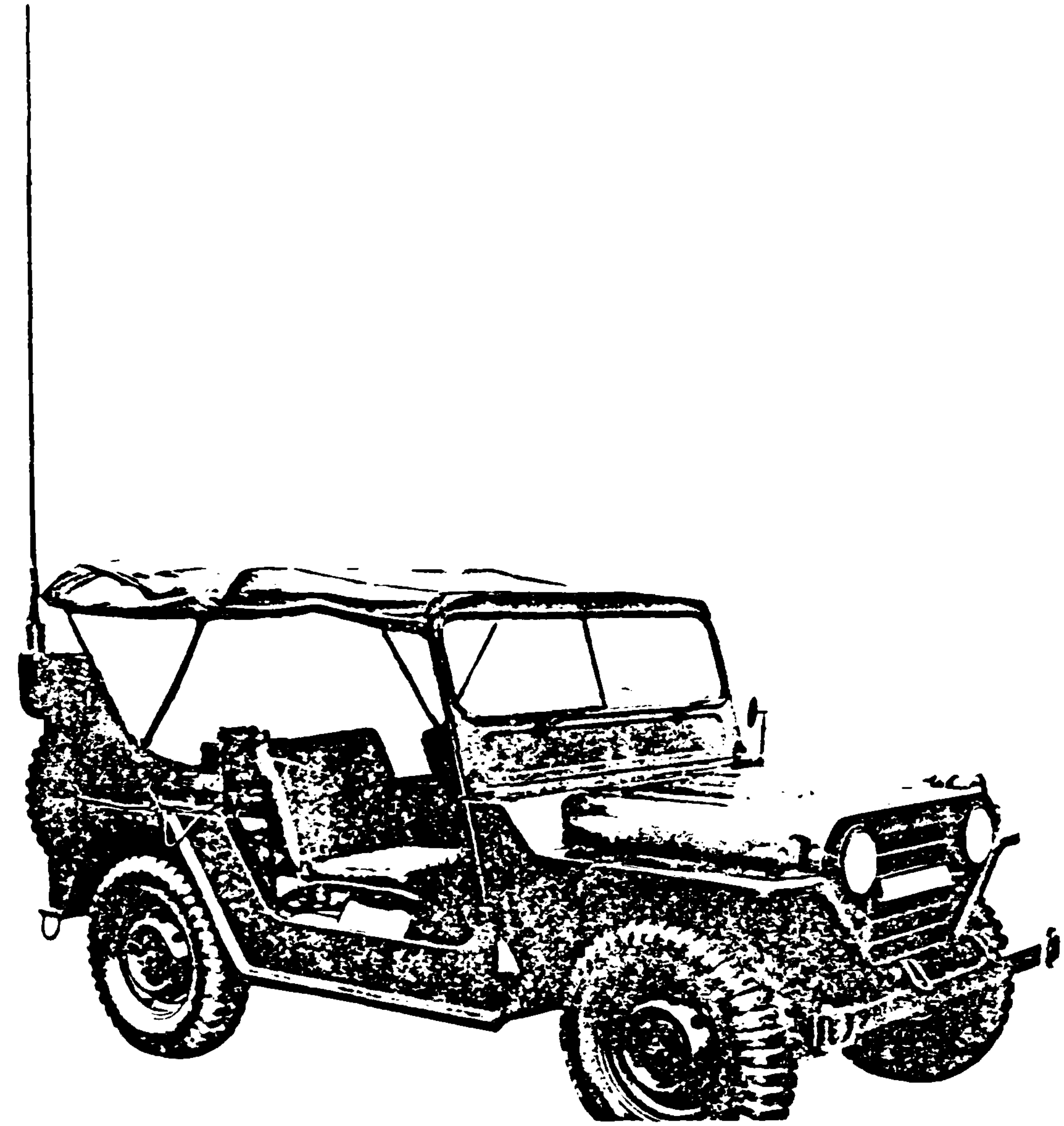


Figure 23 MRC-109 VHF Vehicle

(3) The "Total" configuration was the jeep configuration married to its associated trailer.

(4) The antenna used with all these configurations was the AS-1729, vertically polarized monopole, mounted in the right rear (viewed from the back) of the vehicle.

(5) Effective antenna length: 3 meters.

(6) Operating bandwidth: 30 - 75.95 MHz.

(7) Resonant frequency of operation:

for quarter wave: 23.75 MHz

for half wave : 47.5 MHz

(8) Operational half wavelength range: $.3\lambda - .8\lambda$

Lack of sufficient time precluded an analysis of the antenna matching unit, MX-6706, that is an inherent component of this antenna assembly. Validation tests of a similar antenna assembly, AS-2731, using the AS-1729 as a reference, indicated that the matching unit did perform the required impedance matching [9]. Therefore, it was assumed, as far as loading the model, that no mismatch existed over the frequency range of interest, between the antenna and the radio system.

This report was intended to analyze a discrete sampling of representative vehicle configurations that could be expected to be used in the fleet. These structures were tested over four ground conditions, one ideal, non-realistic operationally, and three conditions of lossy earth.

D. COMPUTER MODEL DEVELOPMENT

One of the most severe limitations encountered in modeling structures surrounding an antenna, when the dimensional quantities of the model are proportionally related to the resonant operational wavelength, is in the determination of a correct thin-wire model. Replacing a solid conducting surface, such as a vehicle chassis, by a wire grid structure imposes difficult assumptions on the design. An implicit assumption here was that sufficiently small grid openings will result in acceptably small electromagnetic differences between the actual solid surface of the vehicle designed and the grid equivalent modeled in the computer.

The program used, NEC, operates within the framework of calculating a numerical solution for the integral equations of currents induced on the segments of the thin-wire model from a voltage source [10]. Input structure data to configure the models was provided to the computer program by generating a segment numbering scheme, segment endpoint locations in space, and selecting an appropriate radius for the thin-wire segments. The models used were all designed and constructed at the highest operating frequency, 75 MHz. This was based solely on the premise that, as the frequency was decreased to 30 MHz, the models would remain effectively accurate. The number of segments for the model would increase relative to the wavelength size. The guidelines for

segment length were the same as those for the RC-292. At 75 MHz, the segment length was chosen to be .381 meters. Around the critical areas of the structure, the antenna feedpoint, the segment length used was .1778 meters. The model radius "a" was chosen to be .0127 meters.

Additionally, with these models a "Numerical Green's Function" capability of the NEC program was applied to make use of the structure symmetry. This option aids in reducing long computer runs associated with large numbers of segments. The number of segments for each model and the average required computer calculations time for that model, are shown below:

Model	Segments	CPU Time (minutes)
basic	191	25
jeep	217	31
total	287	43

A representative sample data input for each model was included in Appendix C. The structure geometry data for each configuration was checked by generating a computer-drawn plot of the wire-grid models. These are shown in Figures 24, 25 and 26.

E. ANTENNA PERFORMANCE ANALYSIS

In analyzing the performance of the variously constructed vehicles, the antenna input impedances were examined as a

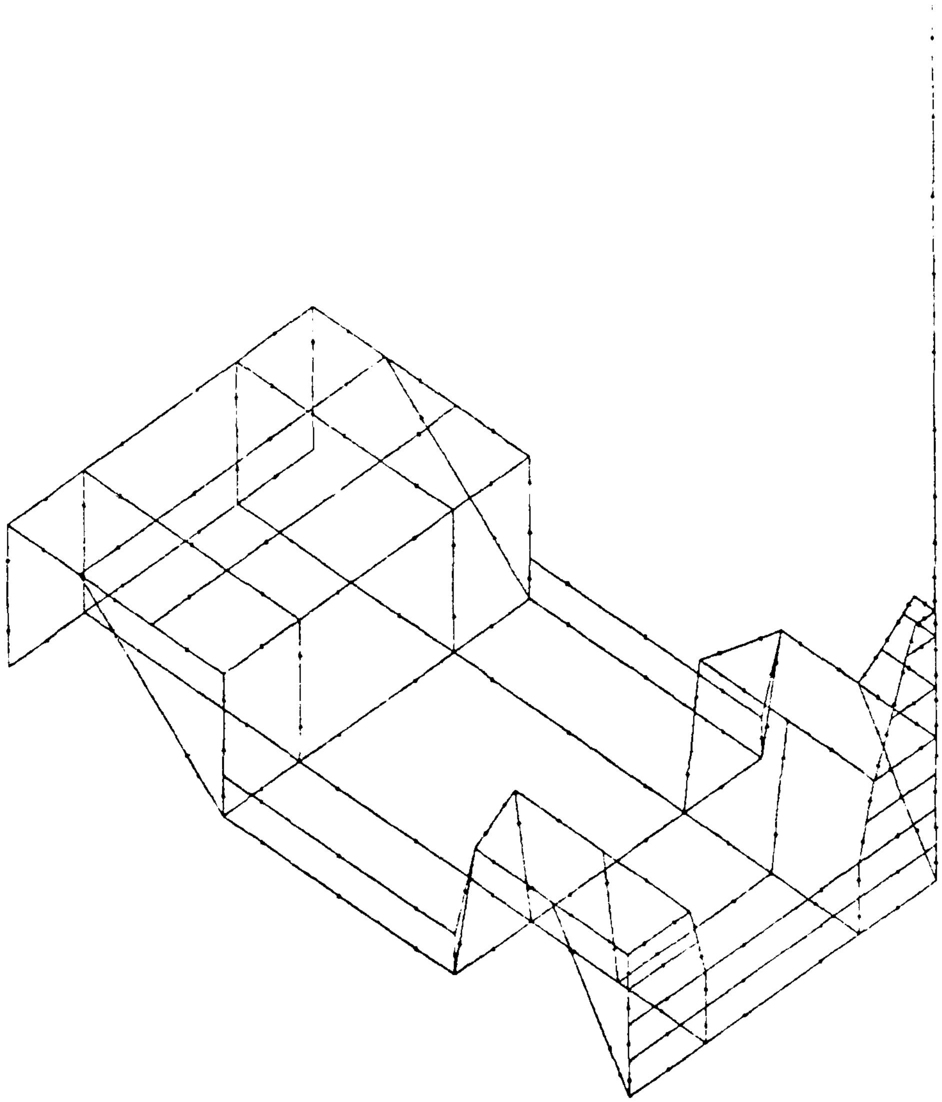


Figure 24 NEC "Basic" Configuration

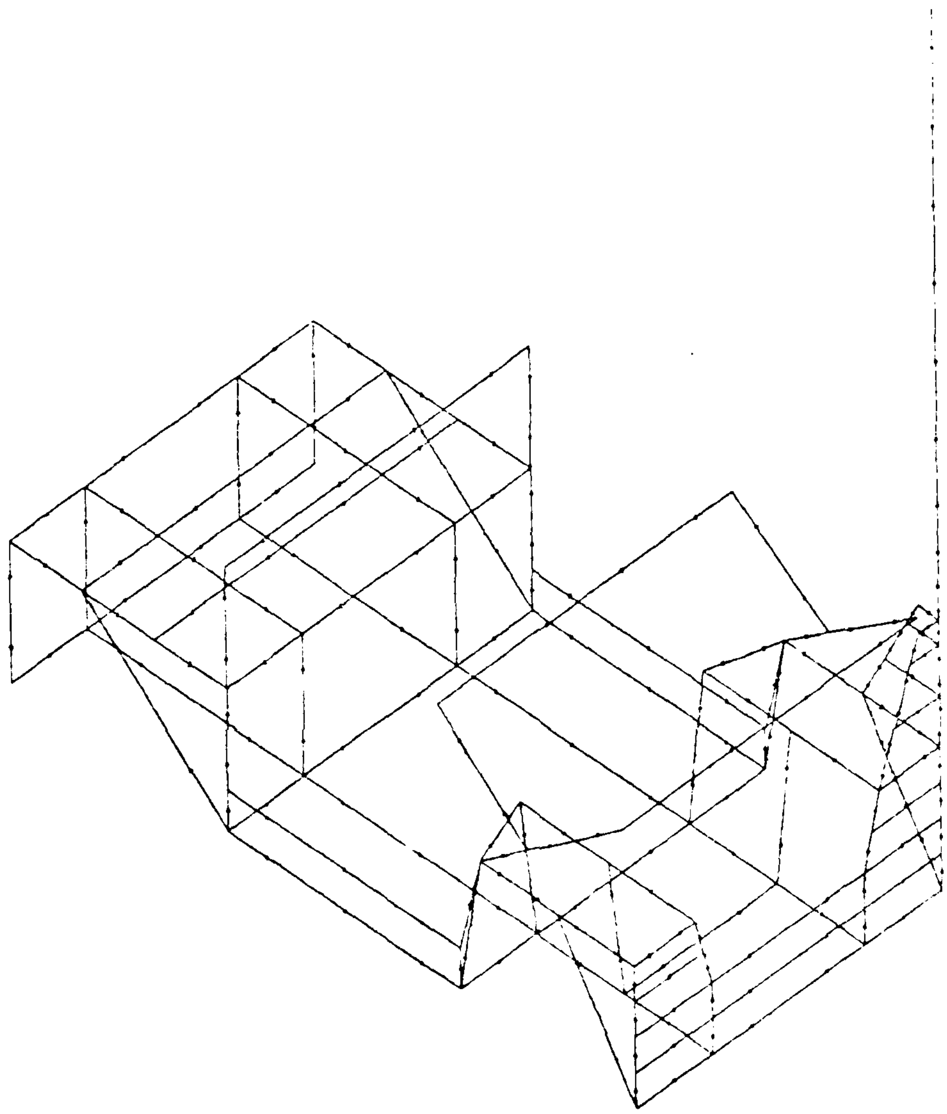


Figure 25 NEC "Jeep" Configuration

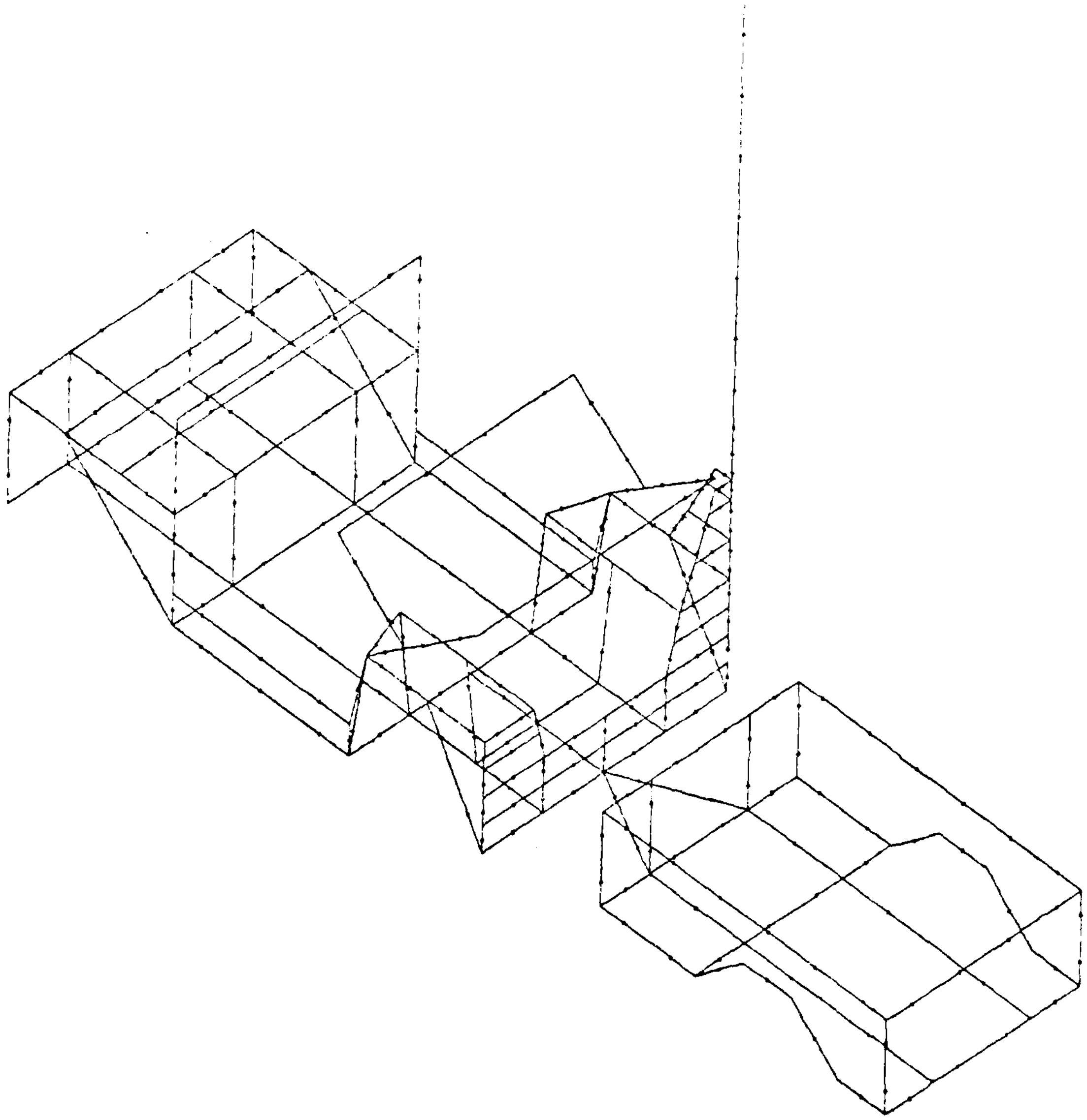


Figure 26 NEC "Total" Configuration

measure of the accuracy of the models. A comparison was made between the results of the NEC programs for each structure as shown in Figures 27, 28 and 29 and the theoretical values for cylinder antennas evaluated by Hallén, as shown in Figures 30 and 31 [11]. The analysis line labeled "200" on these graphs should be used as H/a, length to radius ratio, for the vehicle was 236. The arrows indicate the discrete frequencies used in NEC. An exact comparison was difficult as the vehicle antennas were evaluated only at a few discrete frequencies over a large frequency bandwidth, 45 MHz. However, a substantial correlation in function shape was apparent between the theoretical performance and the computer model. Additionally, the current induced on the antenna was plotted for the "total" configuration operating at 30 MHz. The radius of the vehicle chassis, not the antenna, was varied to compare the effect on the antenna current. The results are shown in Figure 32. This plot contains the correct current distribution for a .3 wavelength antenna. From this figure it was deduced that a source of error encountered in the thin-wire modeling of structures came from obtaining an approximate solution for the currents actually flowing on the structure. It was realized, as the models were developed, that as the segmentation increased (models became larger), that particular models were limited to a selected bandwidth, outside of which, the numerical results obtained became inflated. It was also learned that a design can not simply

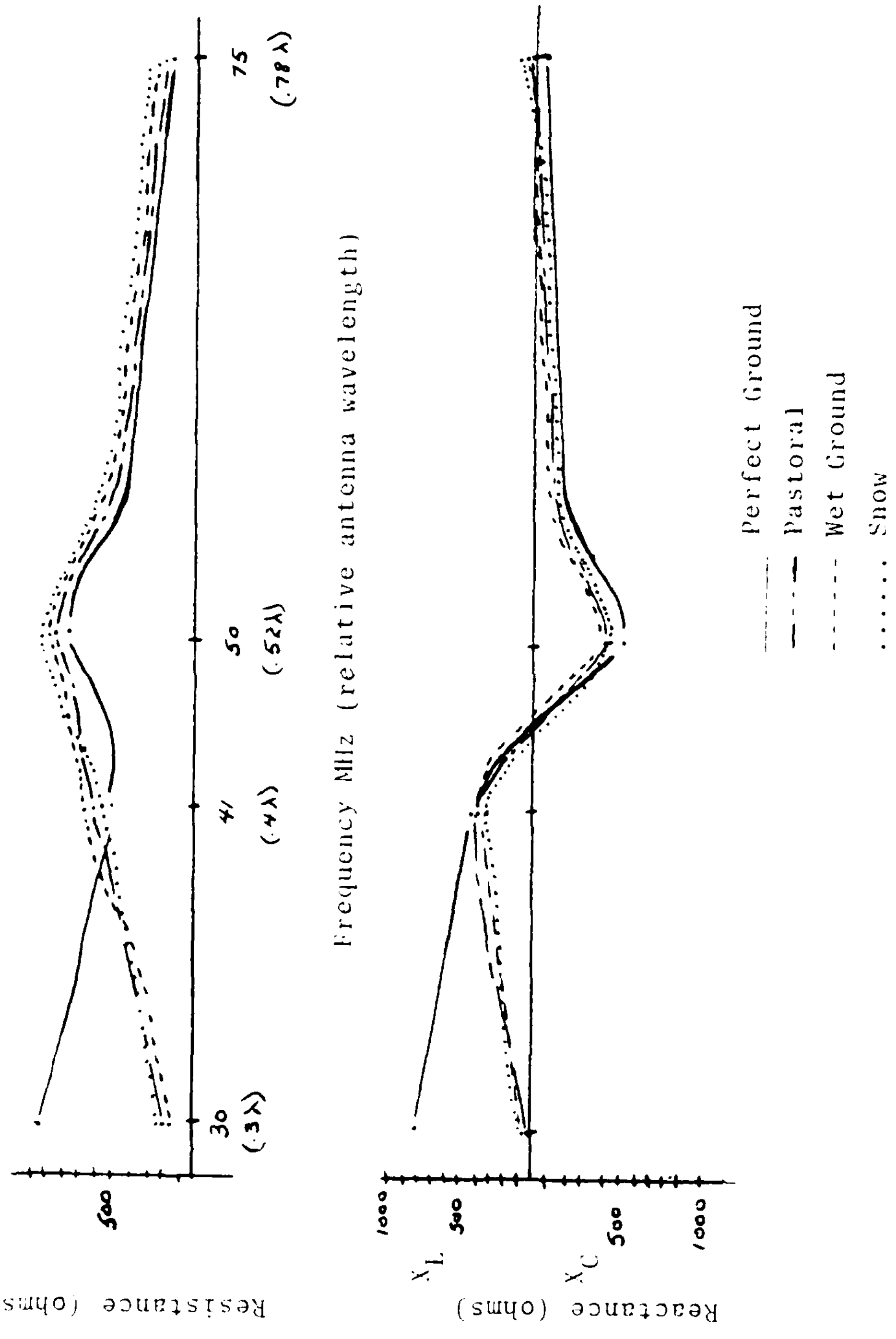


Figure 27 Input Impedance: Basic Configuration

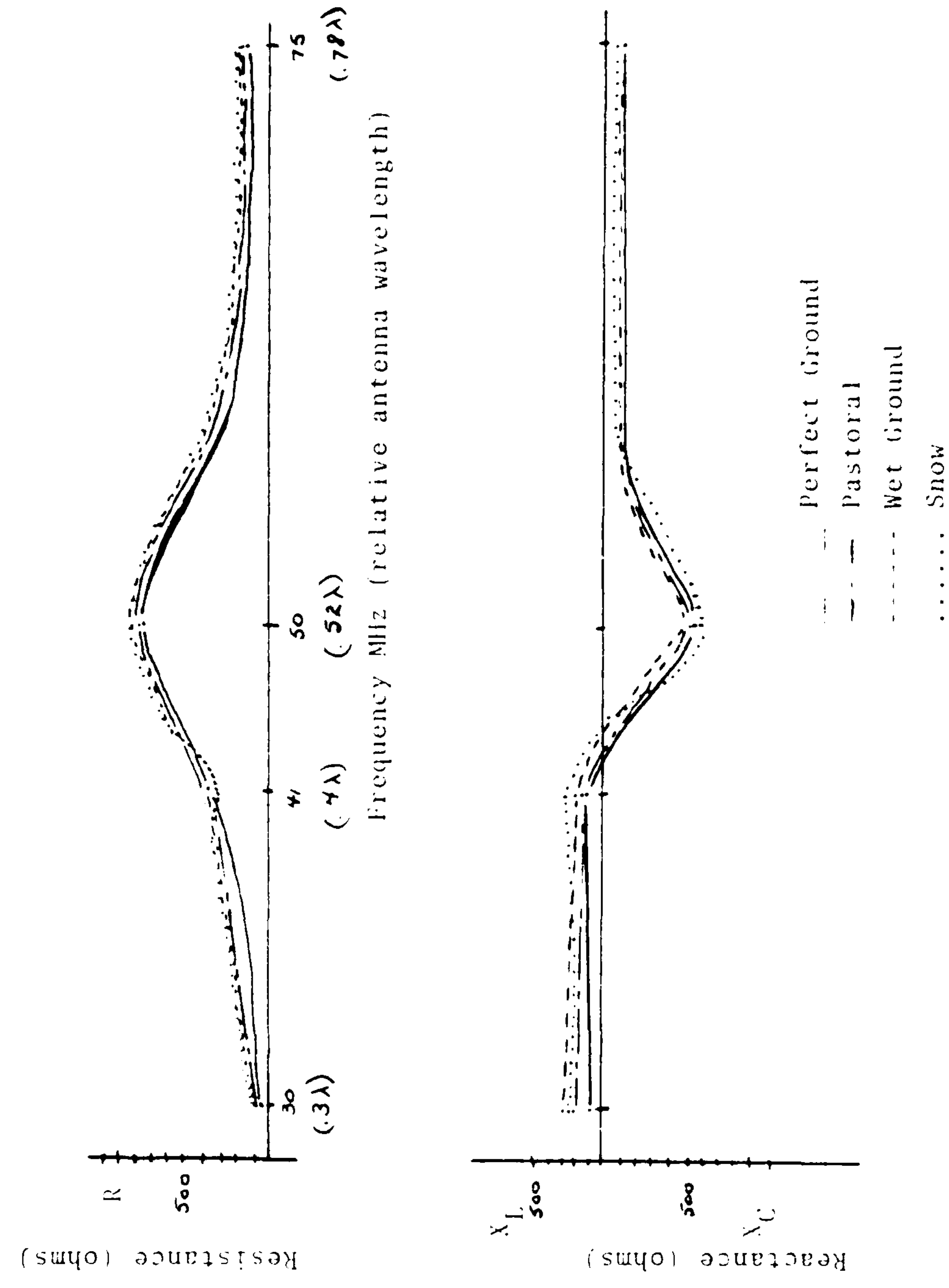


Figure 28 Input Impedance Jeep Configuration

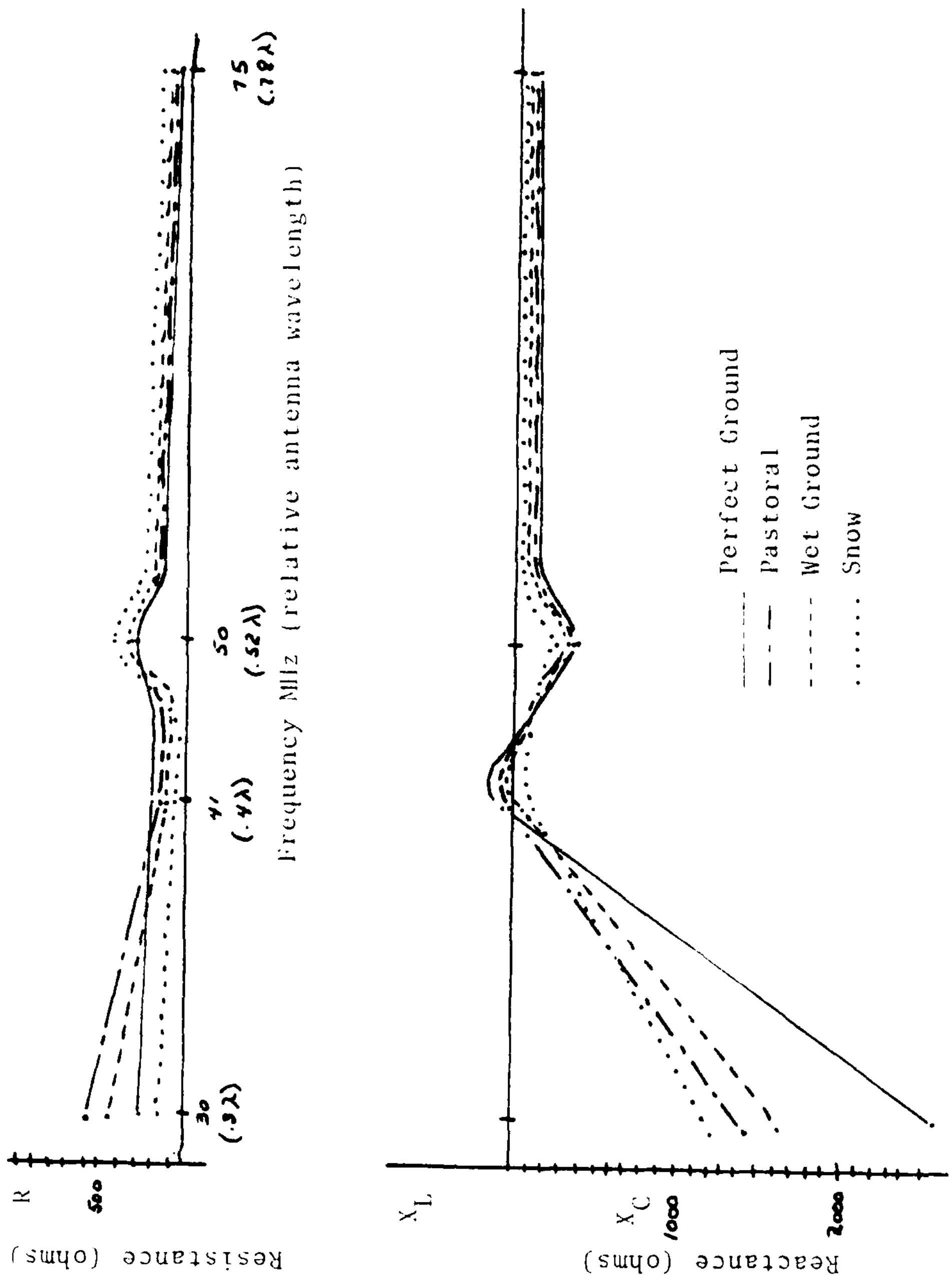


Figure 29 Input Impedance: Jeep and Trailer Configuration

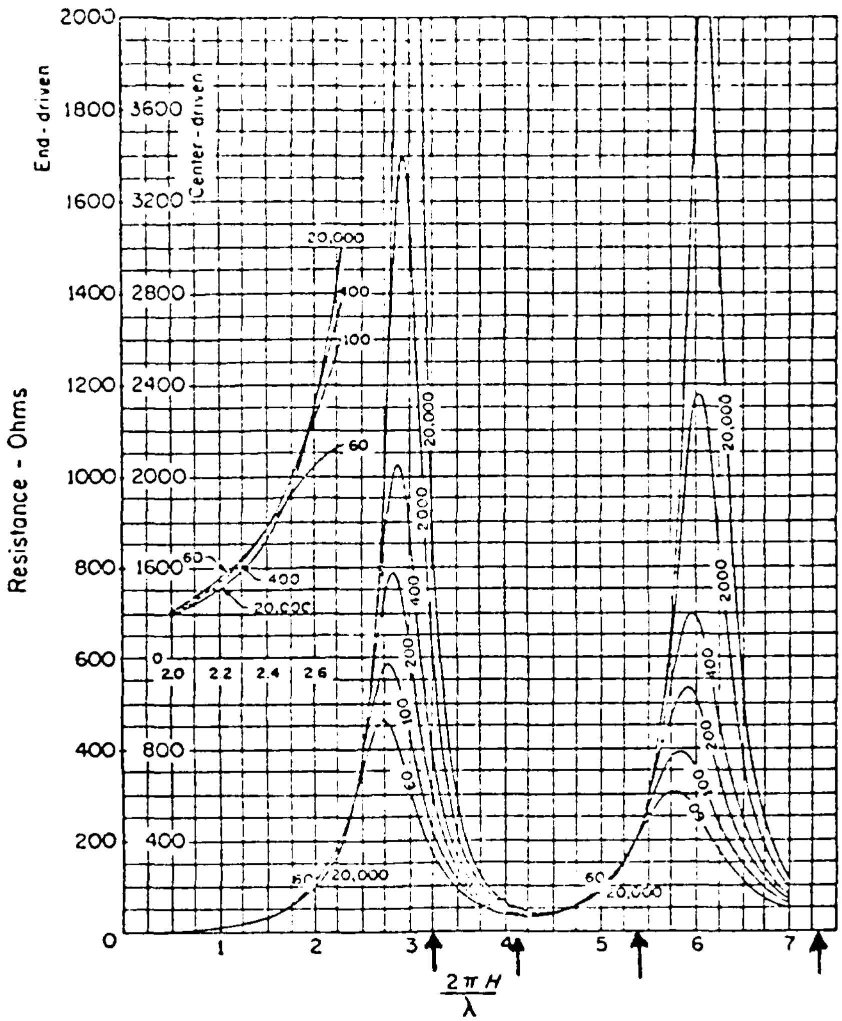


Figure 30 Antenna Resistance According to Hallén

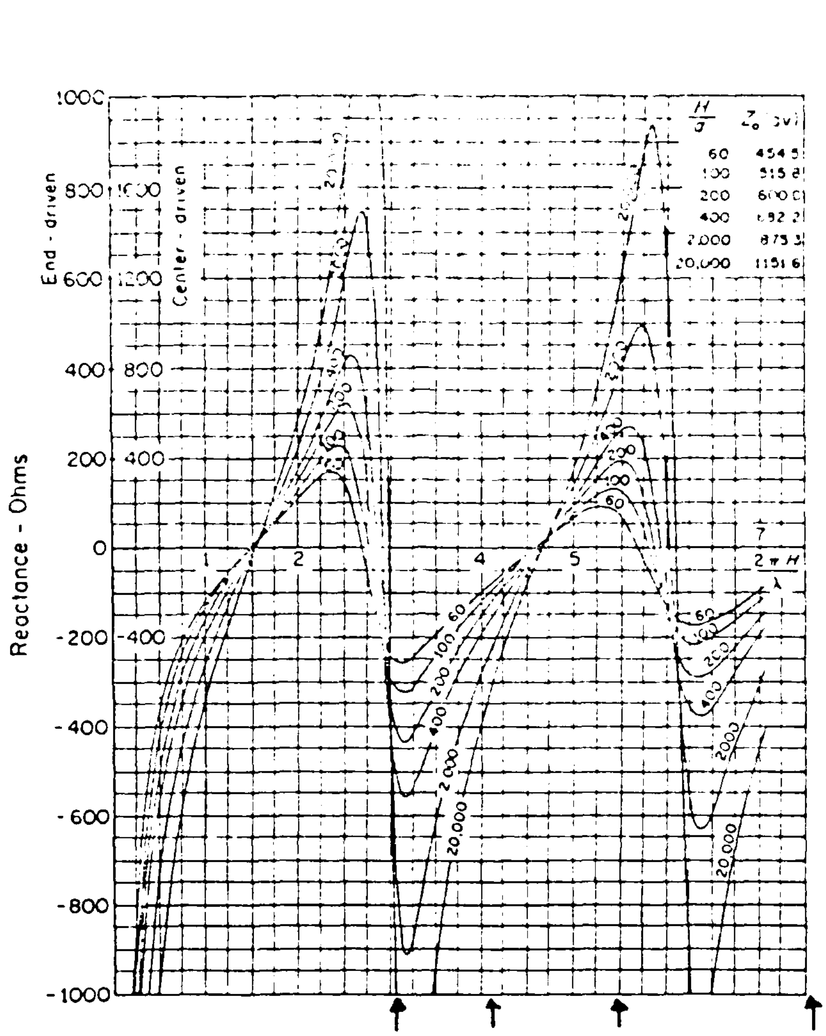


Figure 31 Antenna Reactance According to Hallén

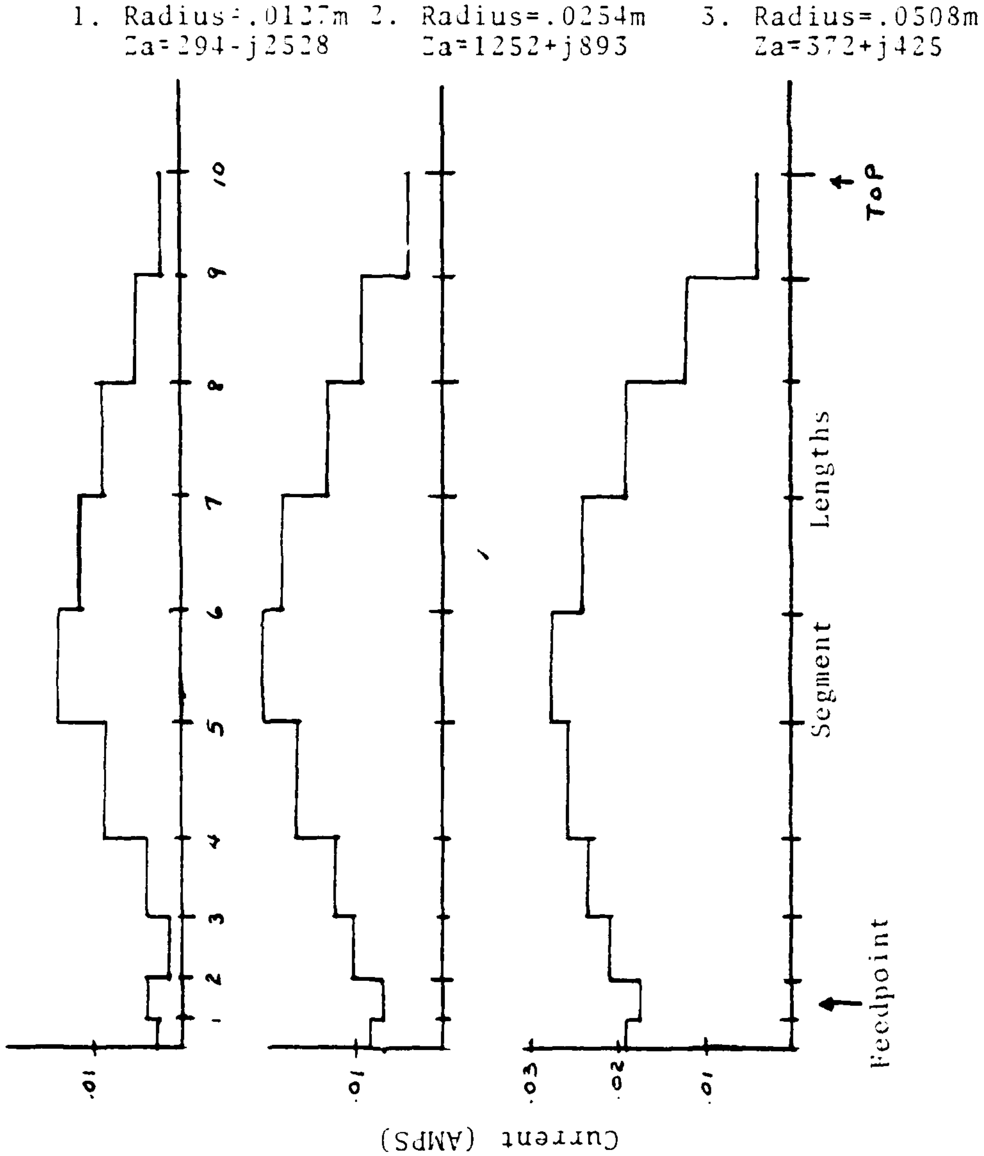


Figure 32 Antenna Current Distribution at 30 MHz for "Total" Configuration With Chassis Radius Varied (antenna radius=.0127m)

invoke one model for a configuration and expect totally accurate results when this model spans a greater than 2:1 frequency range. Accuracy can also be closely approximated by calculating the average gain of the structure. The average theoretical gain over a hemisphere, as the vehicle was modeled over perfect ground, would be 2.0. These calculations require enormous computer assets and time for complex structures. The most complex structure the "total" jeep and trailer was the only structure tested. The average gain calculated at 30 MHz was 2.5036. These results indicated that the models were acceptable and functional approximations for the actual configurations.

F. ANTENNA PATTERNS

Appendix B contains sets of power gain radiation patterns for the three vehicular configurations generated from the analysis of the programs that were run. These patterns were for four discrete frequencies calculated over perfect ground and three operational conditions of dissipative ground. A complete systematic statistical analysis of the vehicular performance was not accomplished due to the inavailability of adequate computer resources and the time involved in such an undertaking. Figure 33 shows a maximum power gain comparison of the three configurations operating over significant ground conditions. A fixed radiation angle, 20 degrees, was selected and the gain calculated at that point was noted.

		Radiation	Angle =	20 degrees
Ground	Freq	Basic	Jeep	Total
	(MHz)	(dBi)	(dBi)	(dBi)
snow	30	1	-2	-3
	41	1	2	3
	50	2	4	2
	75	2	3	2
past	30	0	-2	0
	41	1	0	4
	50	2	2	3
	75	3	2	2
wet	30	2	2	0
	41	3	3	5
	50	3	0	3
	75	4	2	2

Figure 33 Maximum Gain For A Fixed Radiation Angle ($\theta=70°$)

From this comparison it was deduced that the "basic" configuration resulted in less deviations of gain over the frequencies and grounds analyzed.

Figure 34 shows the variances that resulted in the angle of maximum radiation between the configurations. These figures indicated that there was a variance of as much as 4 dB between configurations at an angle 20 degrees from the horizon. The configuration that indicated the least variance over the range of frequencies analyzed and ground conditions investigated, was the "basic" configuration. It also showed the most desireable overall omnidirectional pattern. A comparison of the horizontal patterns of the three configurations in the appendix illustrated the sharp differences. Figure 35 clearly shows the nulls that occurred in pattern of the "total" structure. These nulls are a result of the destructive interference and reradiations from not only the trailer but also the canvas brace and windshied. Operation of the antenna system with the trailer attached therefore, would detract from the system performance. If this system must be operated with the trailer attached (commuting), then fading and distortion can be expected from any signal oriented along the axis eminating from the driver side of the vehicle. A decrease can be expected in excess of 5 dB with an arc of about 60 degrees.

	Maximum Angle		of Radiation	
Ground	Freq	Basic	Jeep	Total
	(MHz)	(angle deg)	(angel deg)	(angle deg)
snow	30	25	25	50
	41	20	20	45
	50	15	15	20
	75	20	15	25
past	30	25	20	20
	41	20	15	45
	50	15	15	15
	75	25	20	20
wet	30	20	15	20
	41	15	15	40
	50	15	45	15
	75	25	25	20

Figure 34 Angle Of Maximum Gain

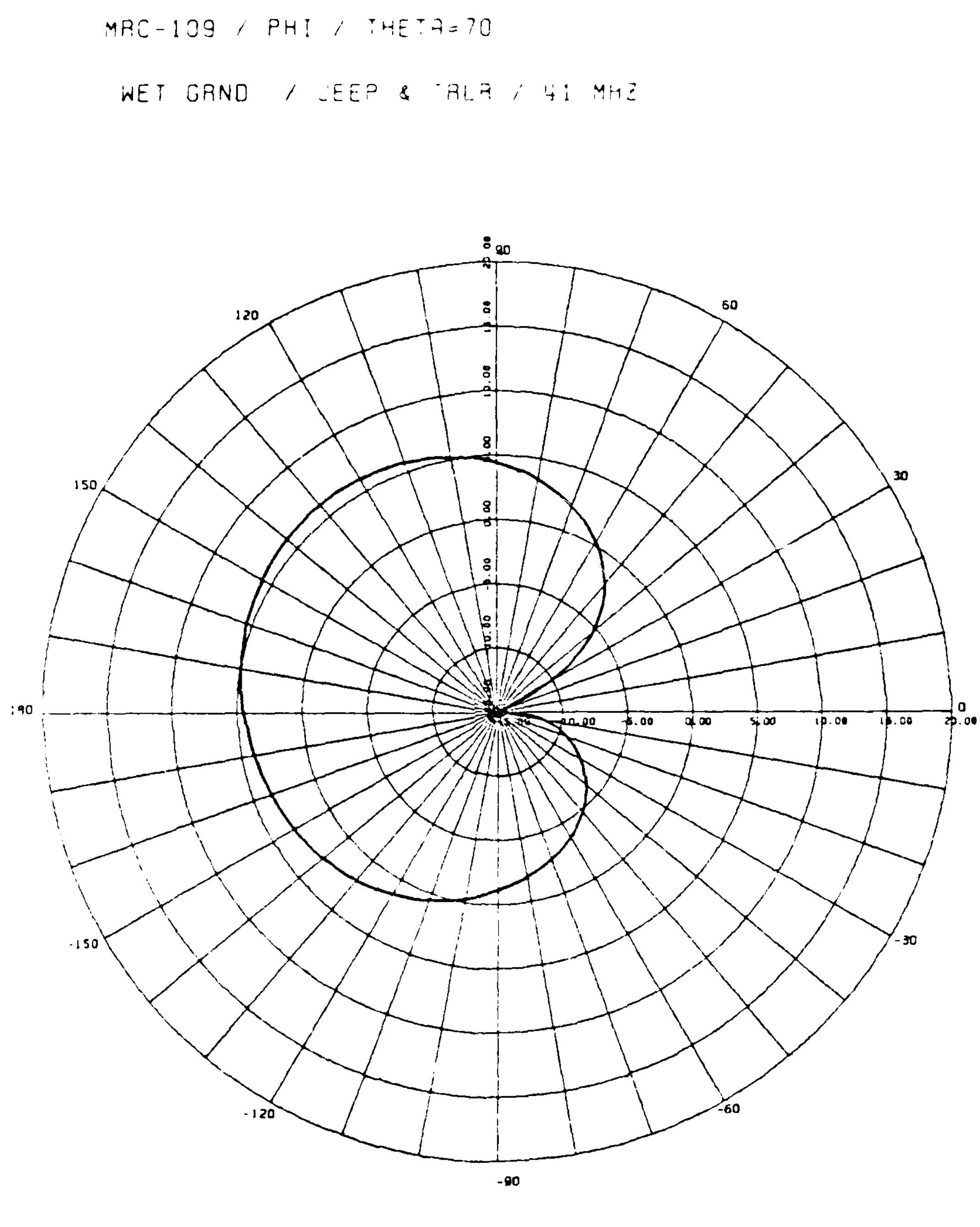


Figure 35 Horizontal Radiation Pattern For Total Configuration. θ=70 degree, freq.=41 MHz

IV. CONCLUSION AND RECOMMENDATIONS

In this thesis an analysis has been presented for two antenna systems presently used by the Marine Corps. The utilization of these antenna systems, as currently configured in a distributed network plan, would place restrictions on the flexibility of the network. Additionally, this study has shown the applicability of the Numerical Electromagnetic Code (NEC) as a cost effective means of analyzing the propagation characteristics of complex structures.

Numerical, experimental and theoretical results were compared, where possible. Agreement was generally very good and this was interpreted as an indication of the accuracy of the models developed.

The first of the antenna systems, the RC-292, was determined to be an omnidirectional antenna over the operational range, 30-75 MHz. The aximuthal plane patterns (θ=90 deg) were within $\pm$ 0.5 dB of being omnidirectional. The elevation plane patterns (ϕ=90 deg) contained a nominal angle of maximum radiation of 10 degrees with a main lobe value of 3 dB. The efficiency of the correctly configured (technical manual) antenna varied from 100 to 44 percent, depending on the frequency used.

The overall significant operational characteristics of the RC-292 are:

(1) The RC-292 would not be an effective or efficient antenna to use in any communication design that incorporated wideband frequency hopping techniques.

(2) When operated at the maximum height of 9.14 meters, the gain and the radiation patterns where not appreciably affected by the condition of the earth beneath the antenna. Attenuation of the pattern will occur as the height is lowered. Greater than 50 per cent of available radiated power can be expected to be lost when the antenna is operated at 3 meters, reducing the range. The angle of maximum radiation will increase from 10 degrees to 20 degrees when the antenna is lowered from 9.14 meters to 3 meters, additionally reducing the effective range.

(3) Any deviations is constructing the antenna from the recommended operational configurations outlined in the technical manual would result in degraded performance. Constructing the antenna for mid-band operation and operating it through the entire possible range of the antenna system results in an 80 percent overall power loss compared to the technical manual configuration.

The other antenna system analyzed, the VHF vehicular mounted antenna, was a more complex problem. The vehicle chassis, upon which the antenna was mounted, caused reradiations of the power from the antenna, resulting in reshaped radiation patterns. Three possible vehicle configurations were studied at four discrete frequencies of operation over

three dissipative earth conditions. Geometrical symmetries were used to reduce the complexity and the computer run time. The azimuthal plane patterns for the recommended configuration (the basic configuration) varied within $\pm$ 2 dB of omnidirectional. The elevation plane pattern contained a nominal angle of maximum radiation of 20 degrees.

The overall operational significance of this analysis is:

(1) The configuration of the vehicle has a determining impact on the overall radiation pattern generated from this antenna system. The recommended vehicle configuration would be the operation of the jeep without the the trailer attached, with the windshield down and the canvas brace off. Inclement weather would make this impossible, however, replacement of these items with dielectric material would eliminate this problem.

(2) Operation of the vehicle with the trailer attached should be avoided. Nulls in the pattern and loss of quality communications can be expected along the axis perpendicular to the driver, for an angle of 30 degrees either side of this axis.

(3) Degraded performance in the system can be expected when operating over snow or desert conditions. The condition of the earth has an effect on the performance, with as much as 40 percent loss in snow.

The overall recommendations from this study are that:

(1) It is necessary, when using thin-wire modeling techniques for vehicular systems, that the segmentation be appropriately varied when the operational frequency bandwidth exceeds a ratio of 2:1.

(2) Brass scale model testing should be done for the vehicle configurations to enable a correlation between the numerical results and measured results.

(3) A probabilistic system analysis be done on the vehicular structures for a total performance understanding.

(4) Modeling of these vehicles at HF frequencies should be accomplished using the Sommerfeld option within NEC, as the Fresnel reflection coefficient option indicated inflated results at the low frequency analyzed, 30 MHz.

(5) Follow-on antenna systems, such as the OE-254, should be analyzed with the same techniques outlined here.

APPENDIX A

Contained in this appendix is a listing of the radiation patterns generated by the NEC computer analysis for the RC-292 ground plane antenna. The heading for each radiation pattern contains the information necessary for the interpretation of the pattern. The first line of the heading contains the following:

type antenna / type pattern (phi: horizontal)
(theta: vertical) / plane of pattern

The second line contain the following:

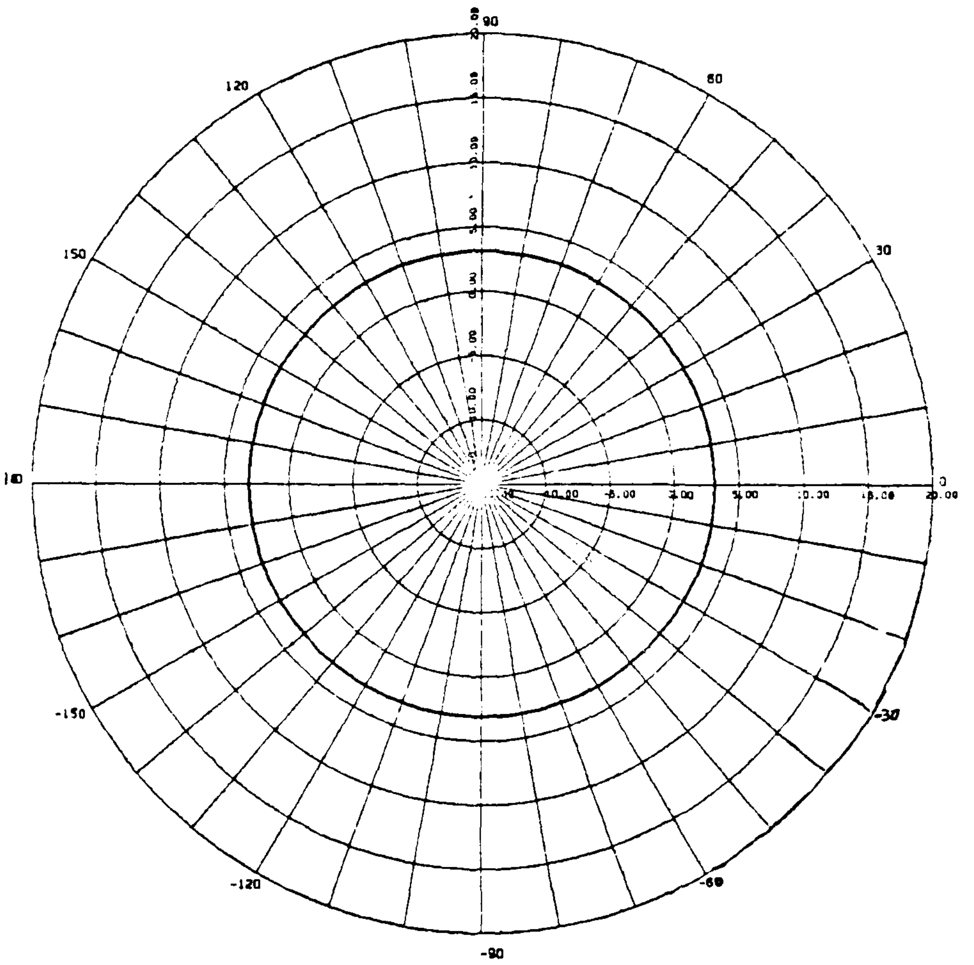
ground / configuration / frequency

The first twelve patterns reflect the directive gain analysis, while the ramaining patterns are power gain calculations for the ground conditions annotated.

The last twelve patterns are the results of the antenna performance over snow, at an antenna height of 3 meters.

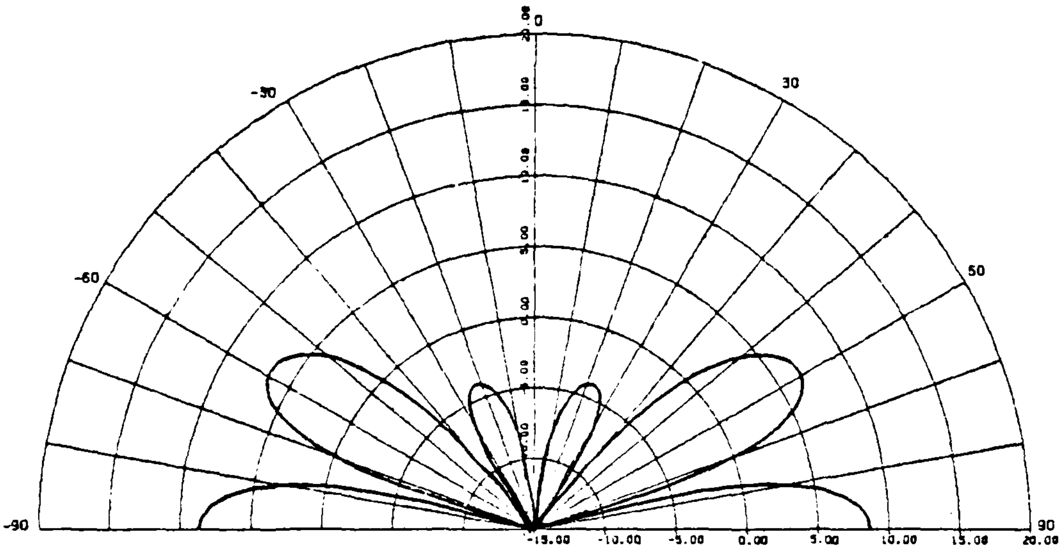
RC-292 / PHI- THETA=80

PERFECT GRND/TECH MANUAL CONFIG/30 MHZ



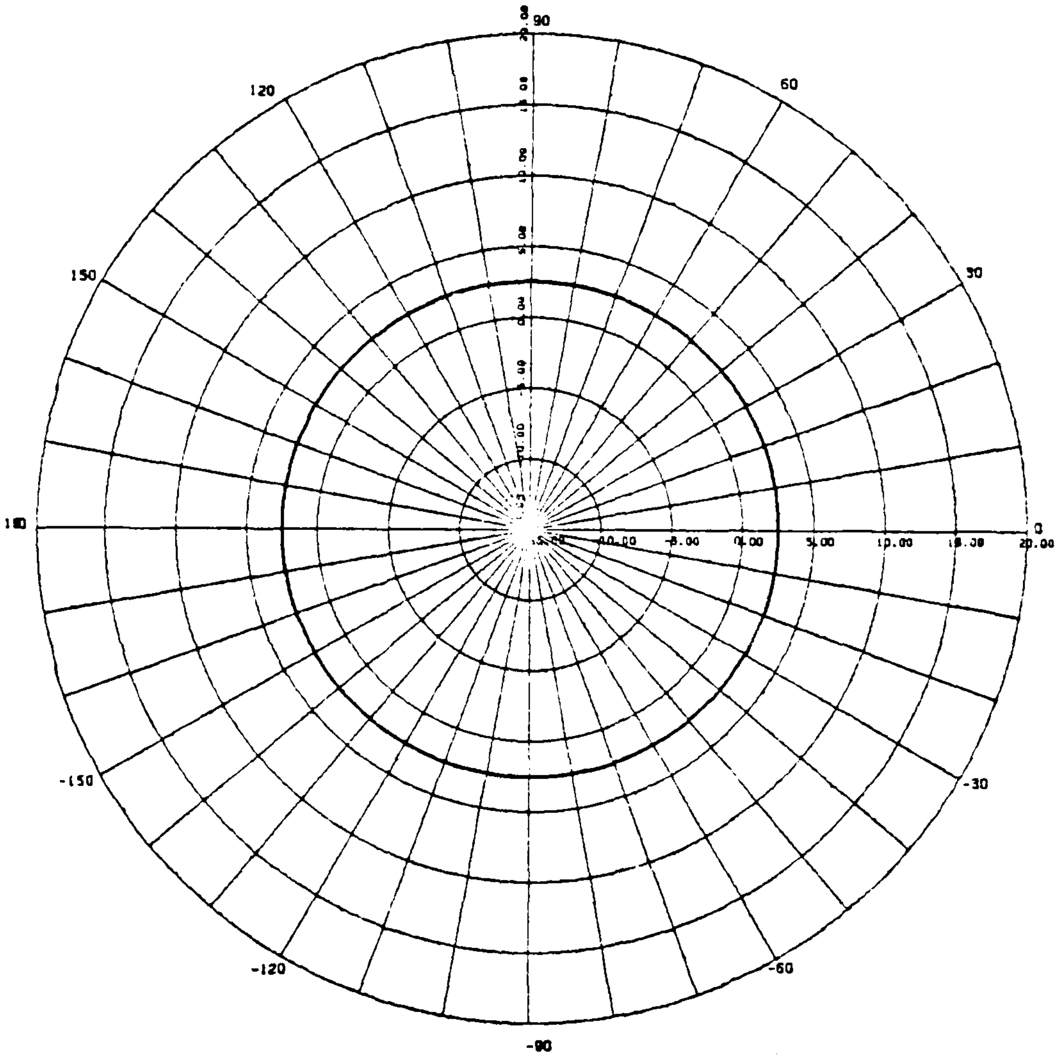
AC-292 / THETA / PHI=90

PERFECT GRND/TECH MANUAL CONFIG/30 MHZ



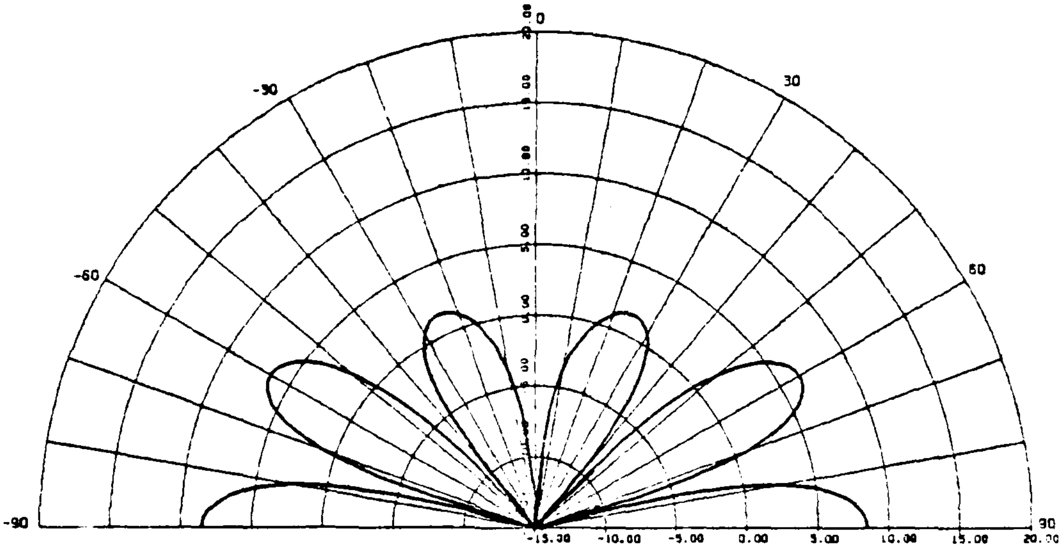
RC-292 / PHI/ THETA=60

PERFECT GRND / TROOP CONFIG /   30 MHZ



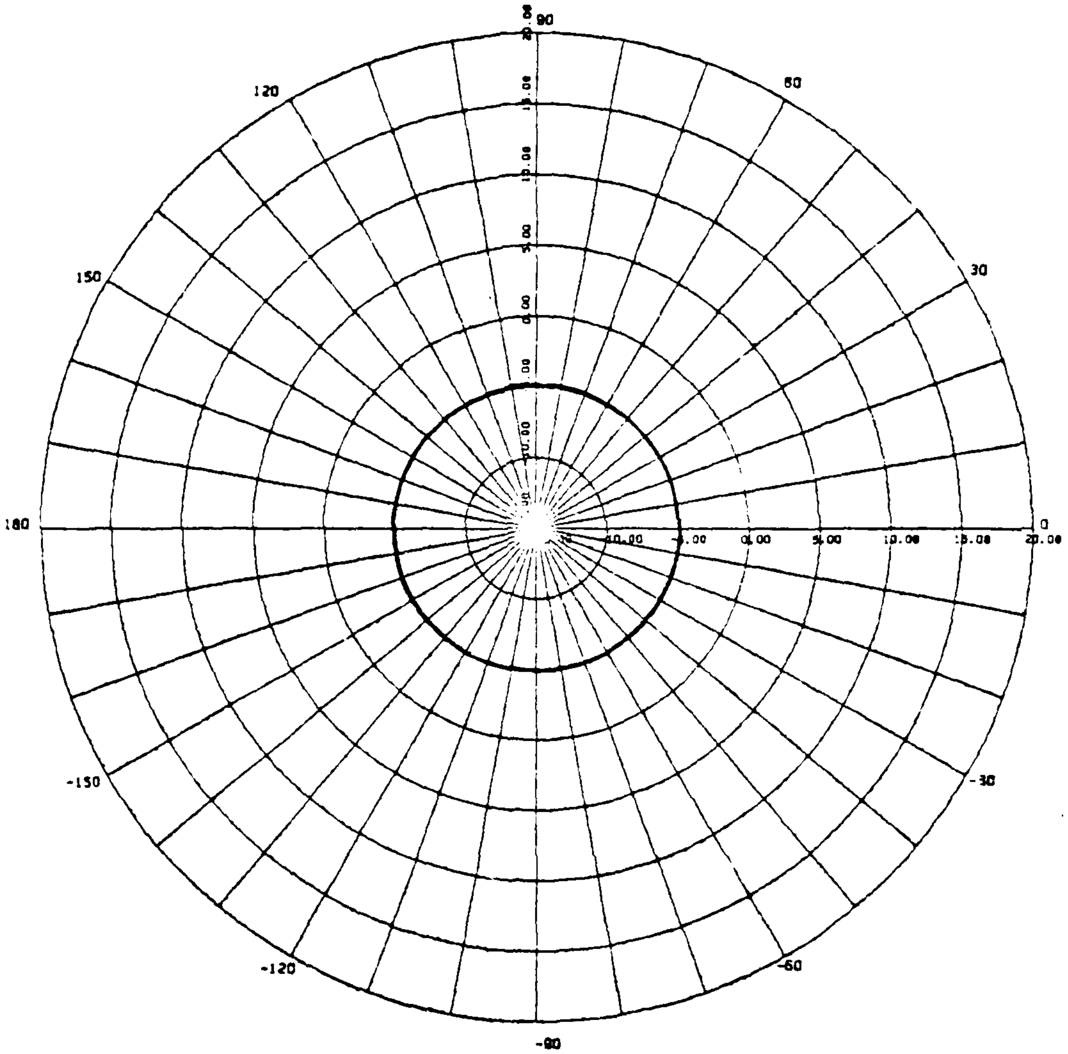
AC-292 / THETA / PHI=90

PERFECT GRND / TACOP CONFIG / 30 MHz



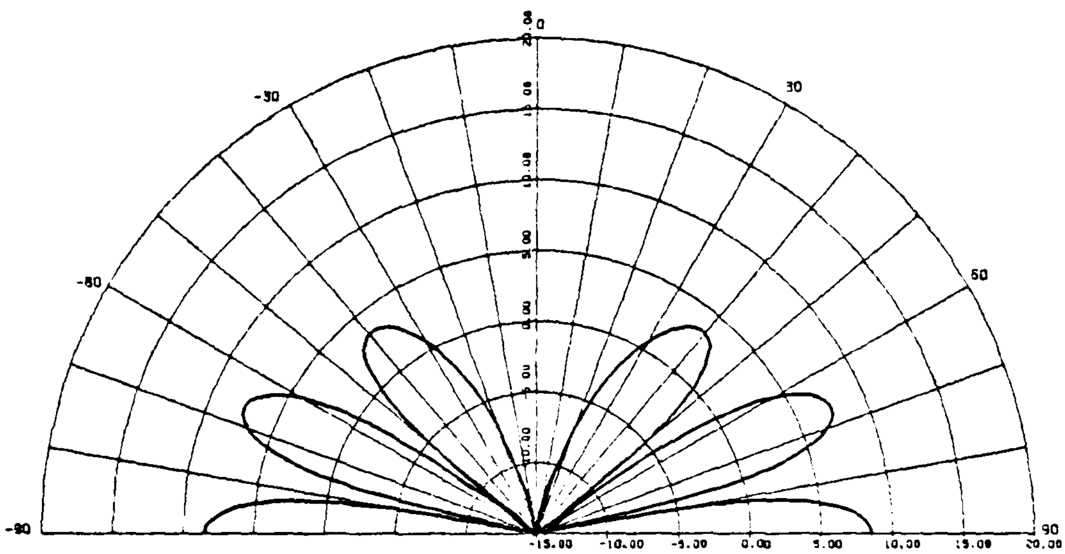
AC-29? / PHI/ THETA=80

PERFECT GRND / MID BAND CONFIG / 41 MHZ



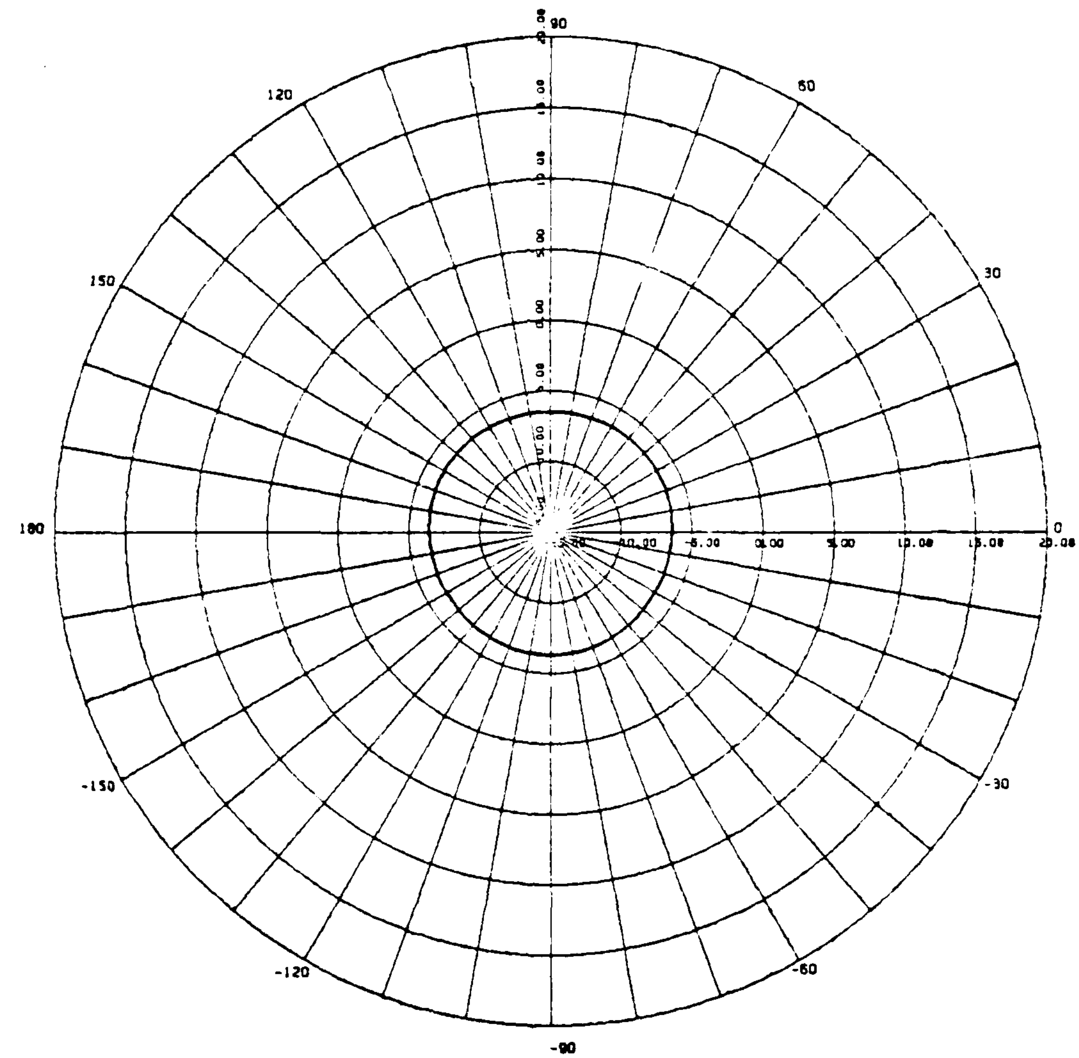
AC-292 / THETA / PHI=90

PERFECT GRND / MID BAND CONFIG / 41 MHZ



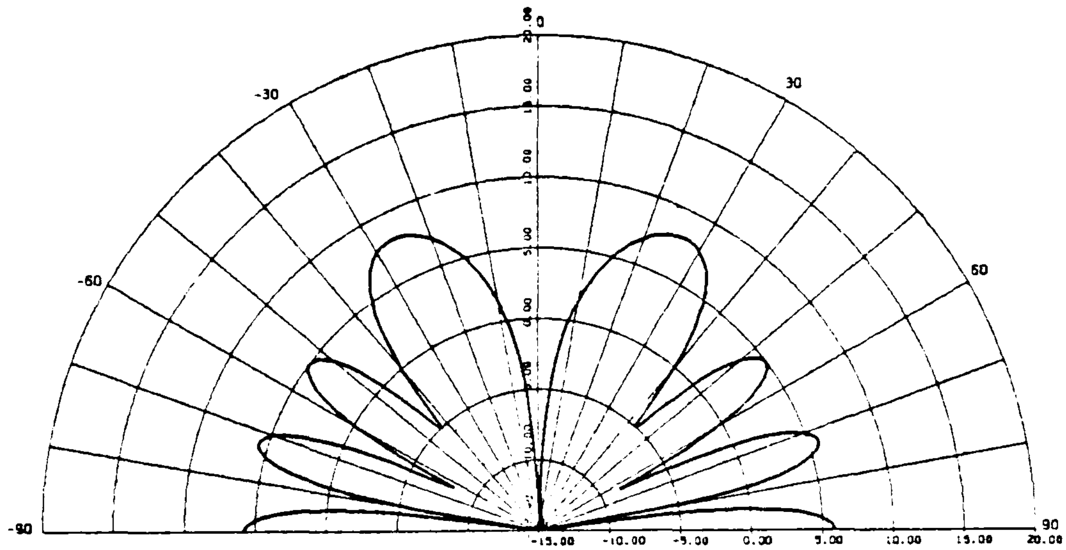
AC-292 / PHI/ THETA-80

PERFECT GRND / MID BAND CONFIG / 50 MHZ



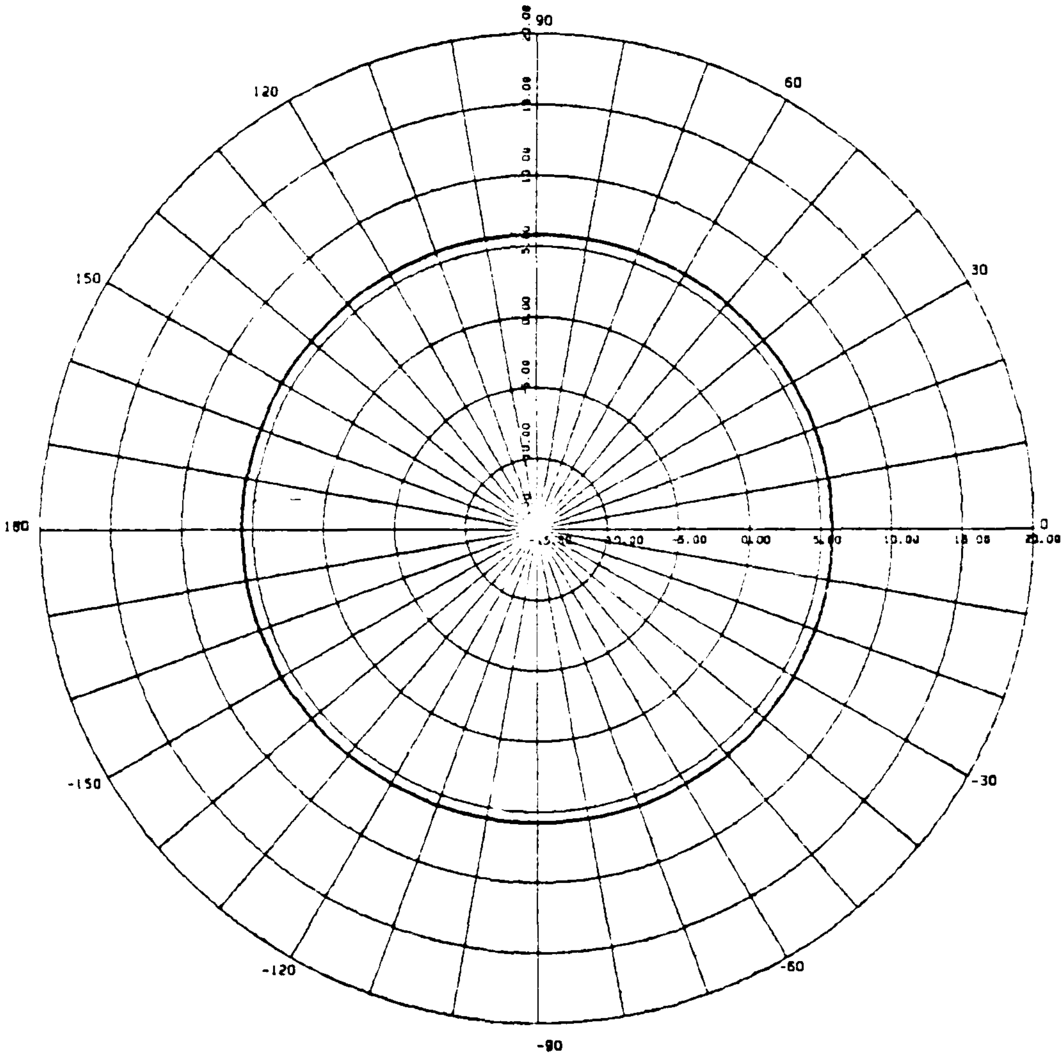
AC-292 / THETA / PHI=90

PERFECT GRND / MID BAND CONFIG / 50 MHZ



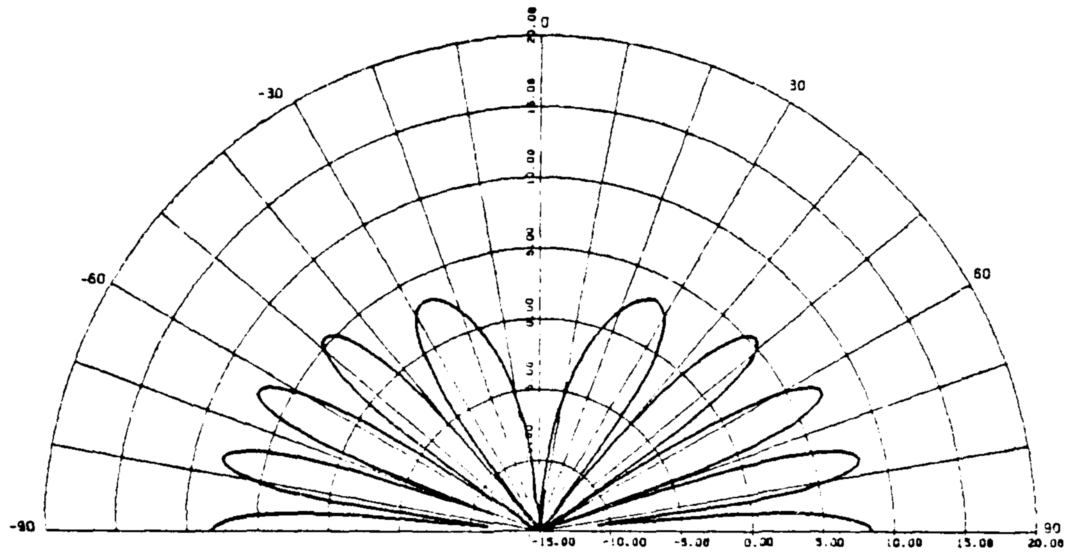
AC-292 / PHI / THETA=80

PERFECT GRND/TECH MANUAL CONFIG/75 MHZ



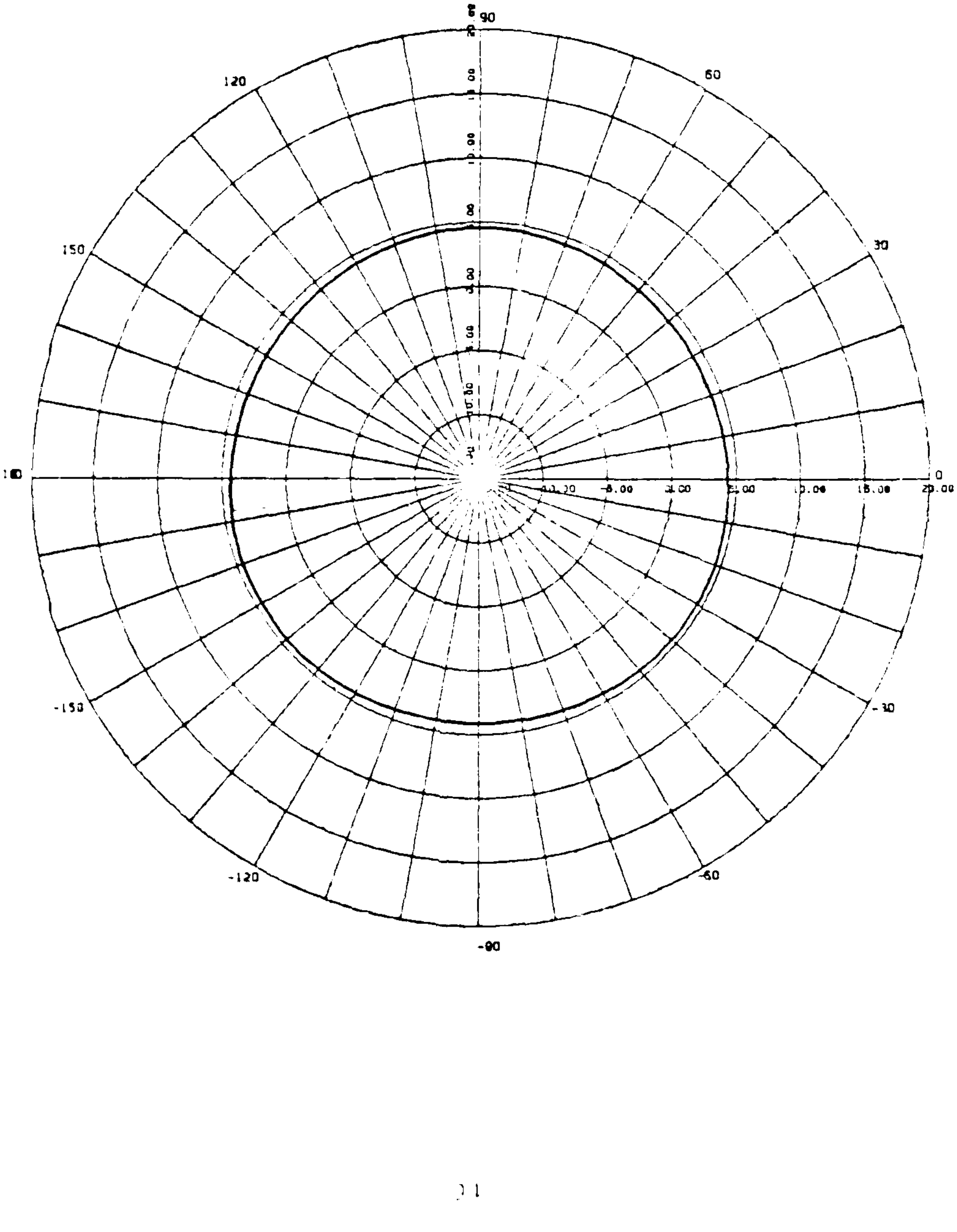
AC-292 / THETA / PHI=90

PERFECT GRND/TECH MANUAL CONFIG/75 MHZ



RC-292 / PHI/ THETA-80

PERFECT GRND / TROOP CONFIG / 75 MHZ



AD-A097 386 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 9/1
UNITED STATES MARINE CORPS TACTICAL COMMUNICATION ANTENNA SYSTE--ETC(U)
DEC 80 W P KEOGH

UNCLASSIFIED NPS-62-80-021 NL

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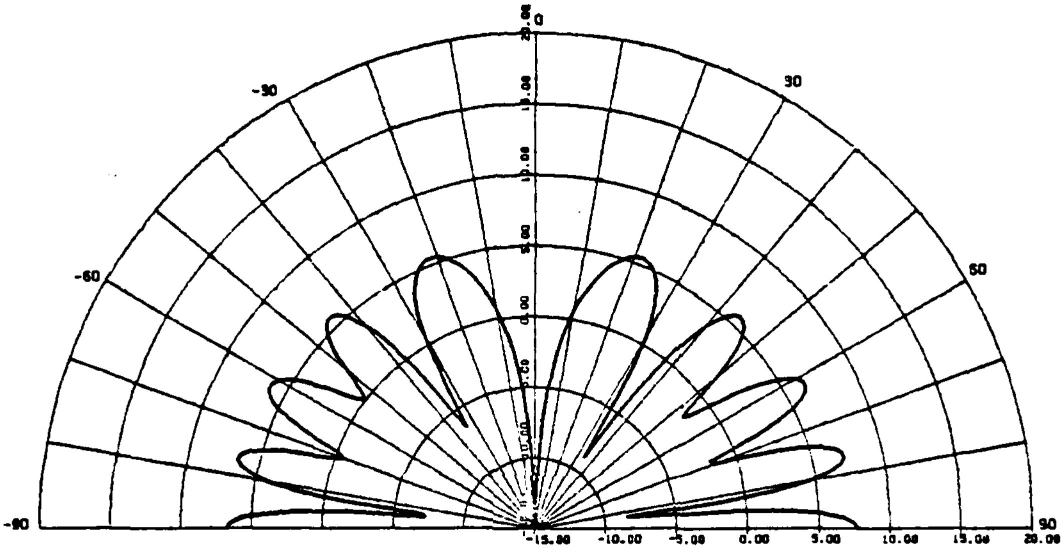
A097386

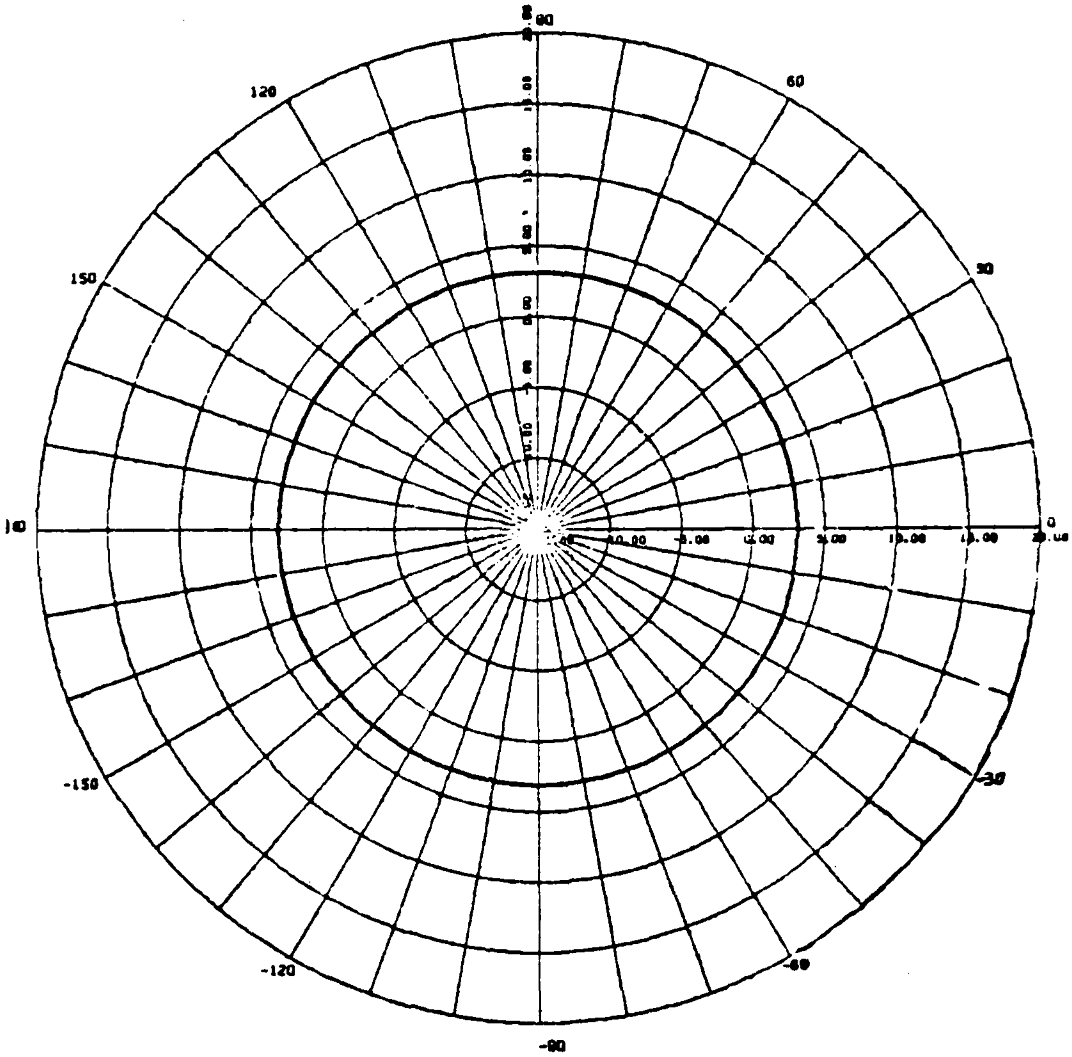
RC-292 / THETA / PHI=90

PERFECT GRND / TROOP CONFIG / 75 MHZ



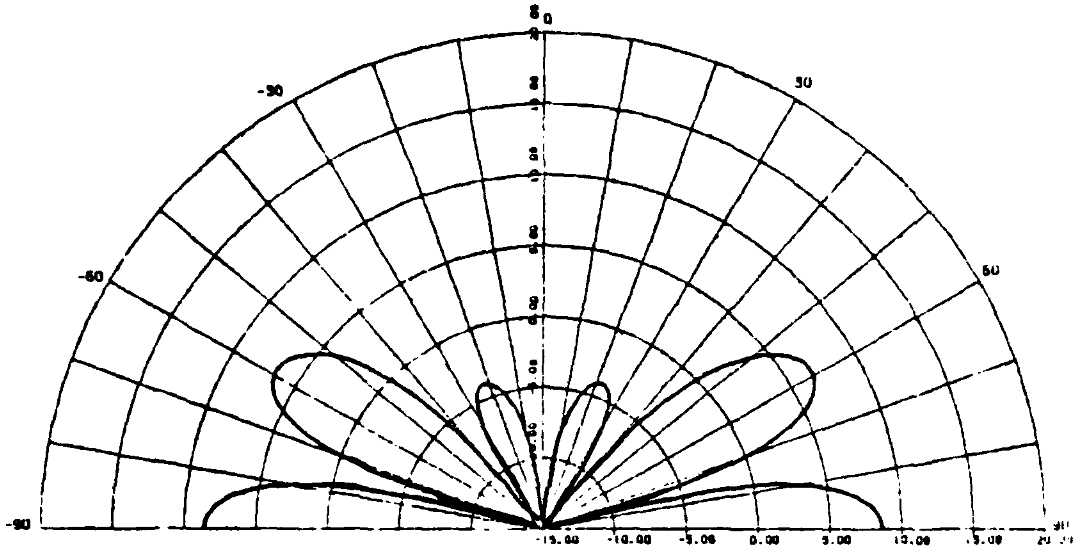
AC-292 / PHI/ THETA=80

PERFECT GRND/TECH MANUAL CONFIG/30 MHZ



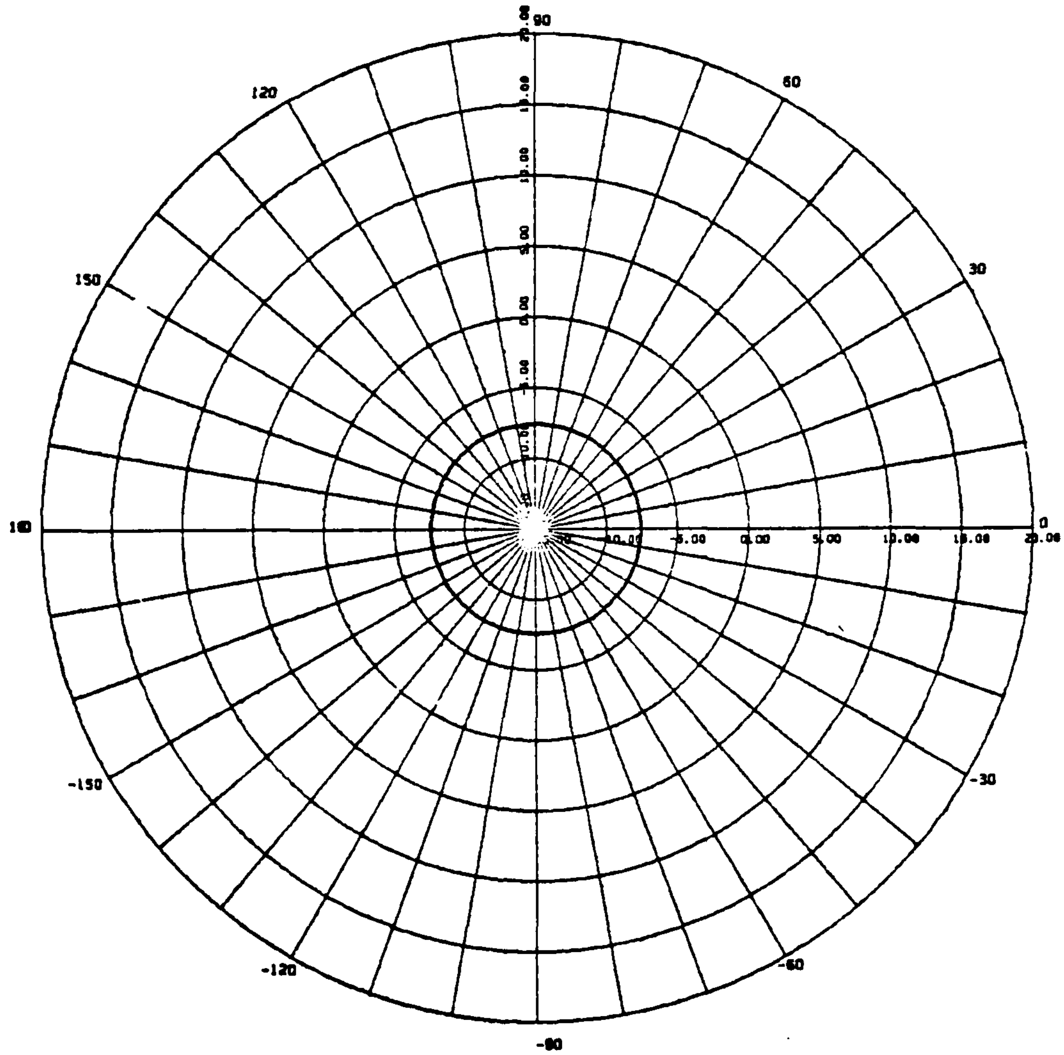
AC-292 / THETA / PHI-90

PERFECT GRND/TECH MANUAL CONFIG/30 MHZ



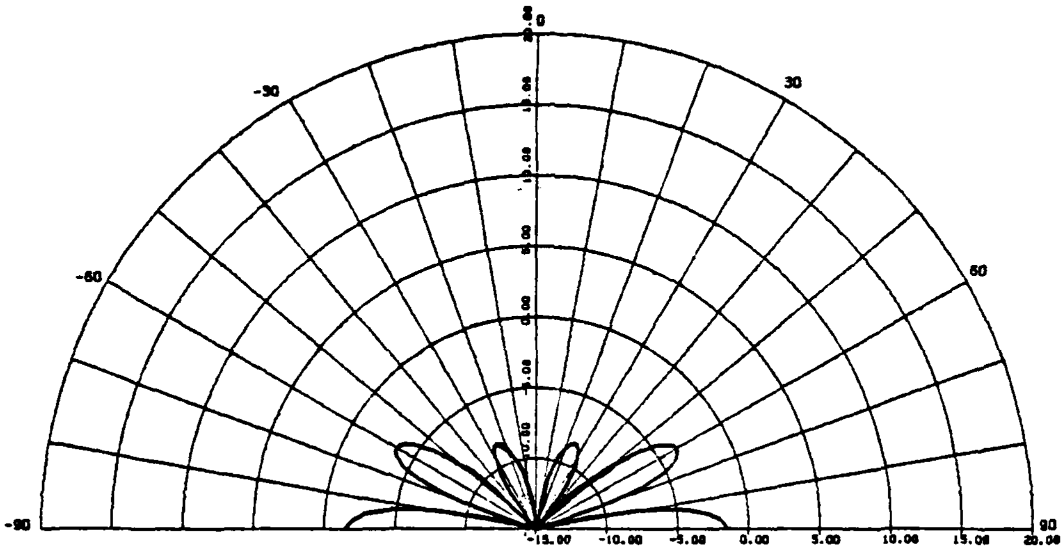
RC-292 / PHI/ THETA=80 (LOADED)

PERFECT GRND / TROOP CONFIG / 30 MHZ



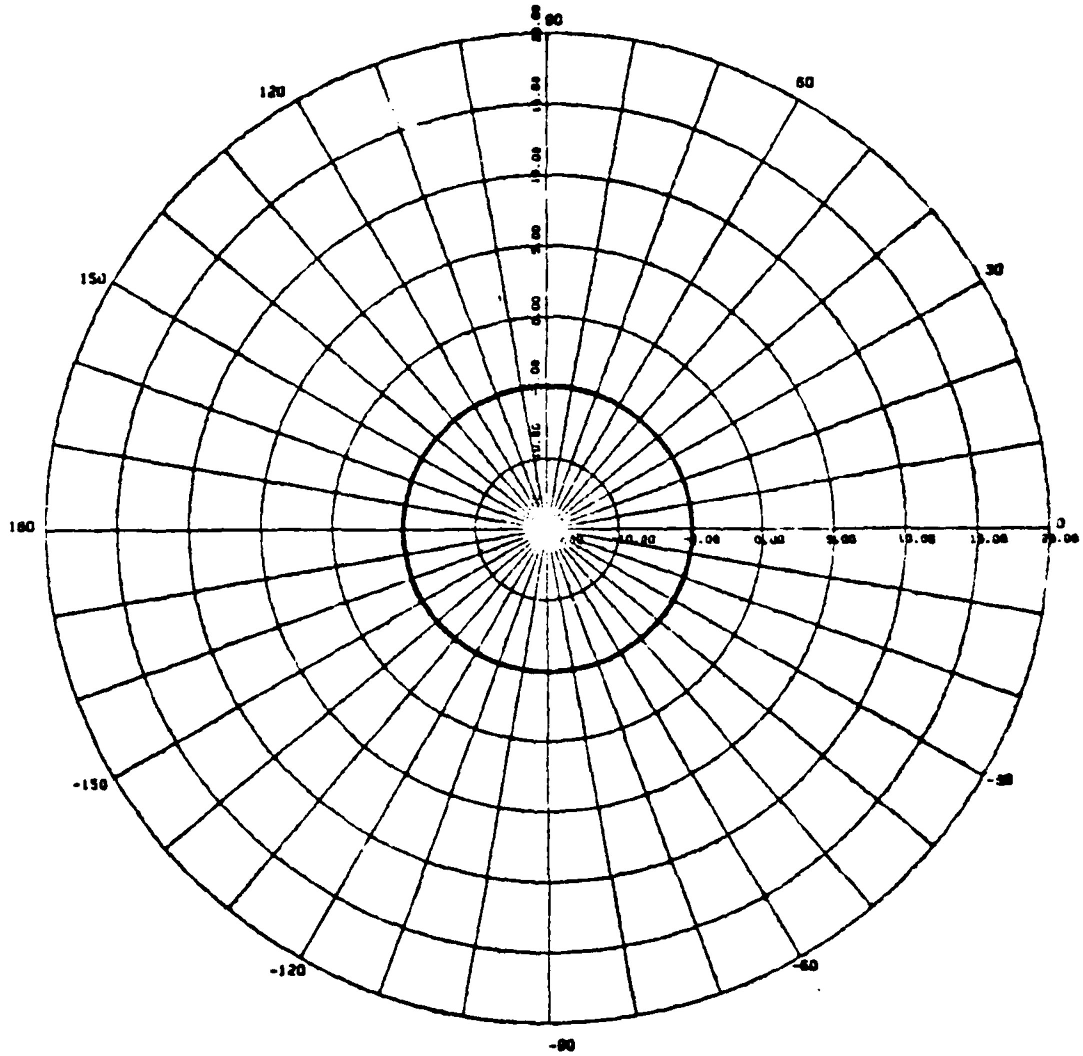
AC-292 / THETA / PHI=90 (LOADED)

PERFECT GRND / TROOP CONFIG / 30 MHZ



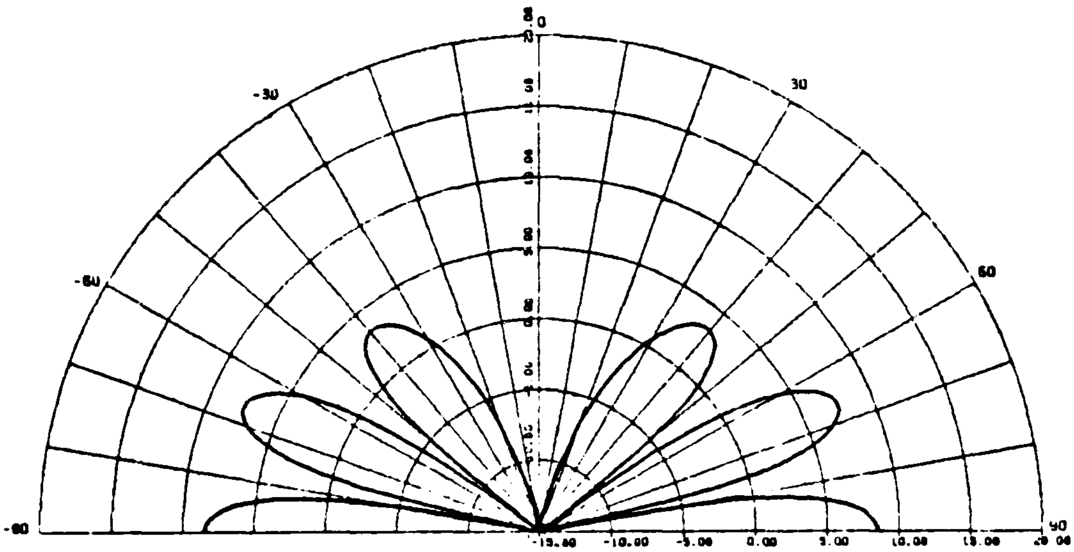
AC-292 / PHI/ THETA 80

PERFECT GRND / MID BAND CONFIG / 41 MHZ



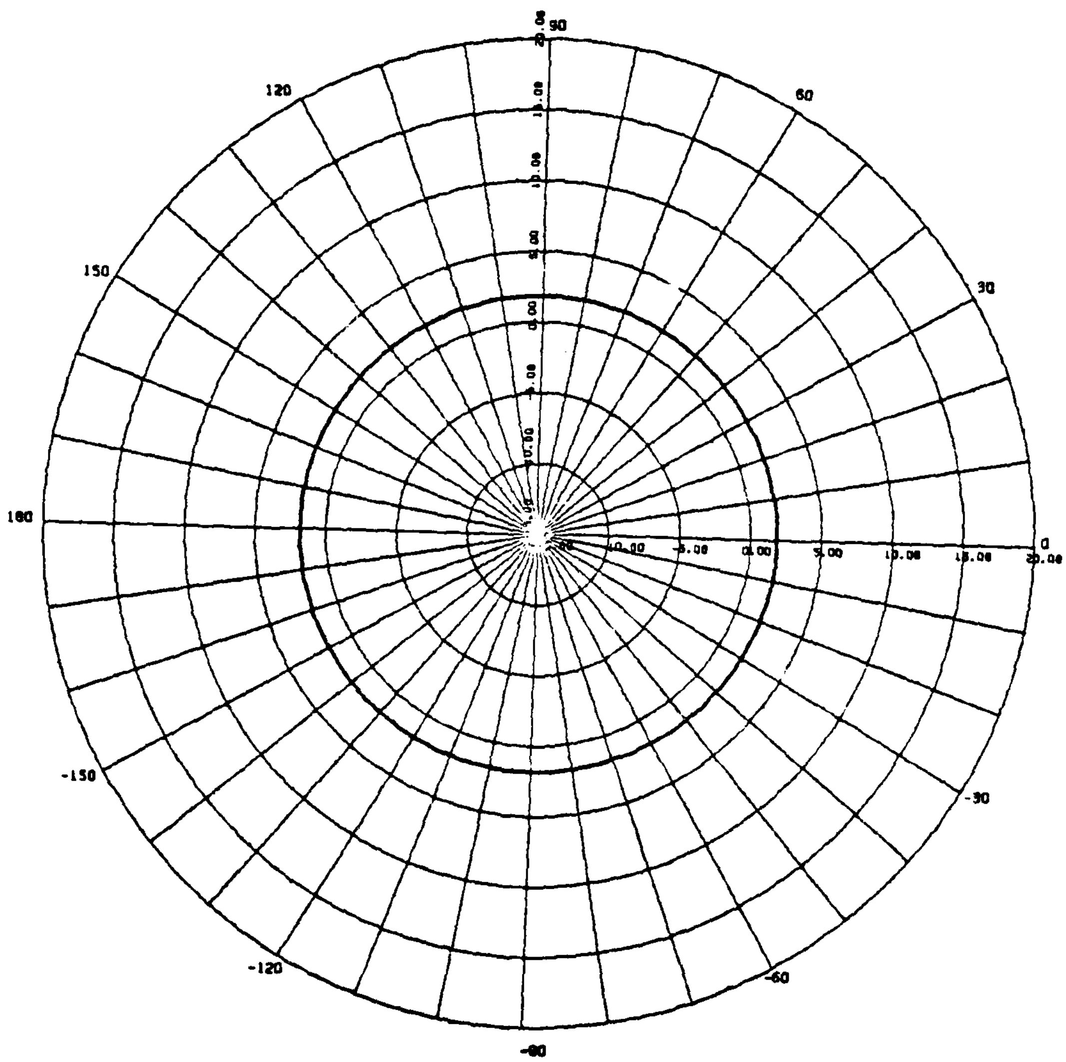
AC-292 / THETA / PHI-90

PERFECT GRND / MID BAND CONFIG / 41 MHZ



AC-292 / PHI / THETA=70 (LOADED)

PER GAND/TECH MANUAL CONFIG/50 MHZ



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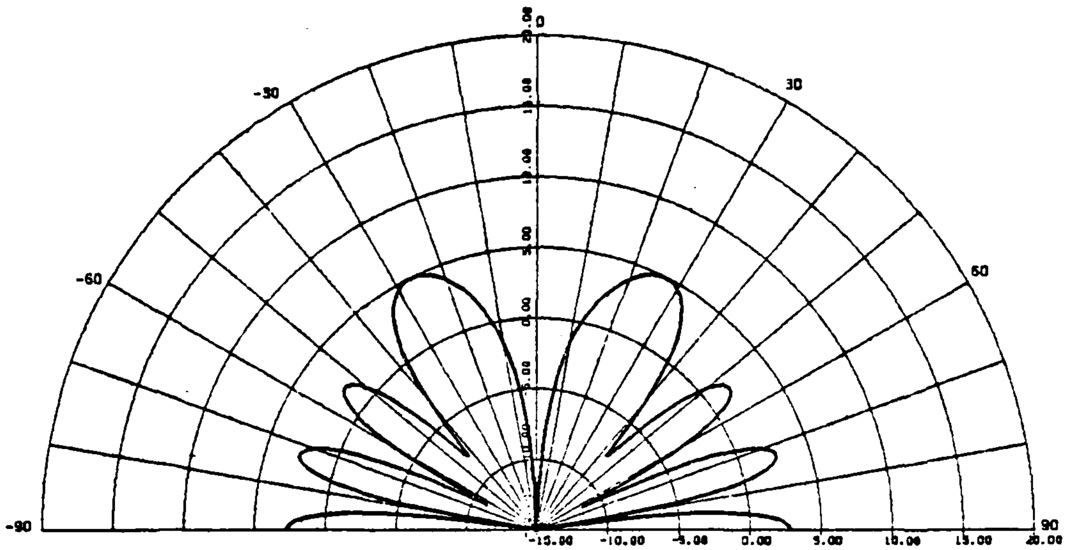
PER GRND/TECH MANUAL CONFIG/50 MHZ



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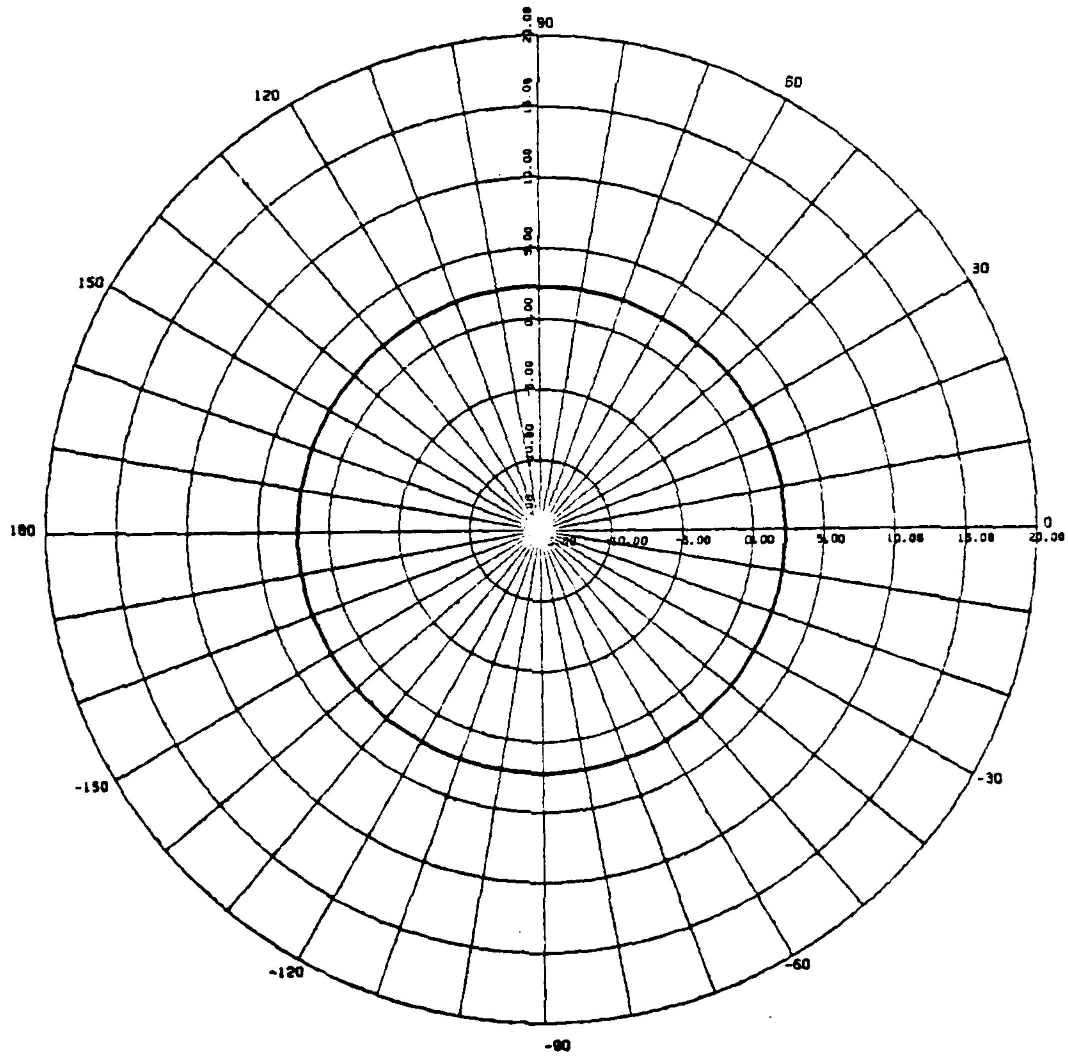
PERFECT GRND/TECH MANUAL CONFIG/75 MHZ



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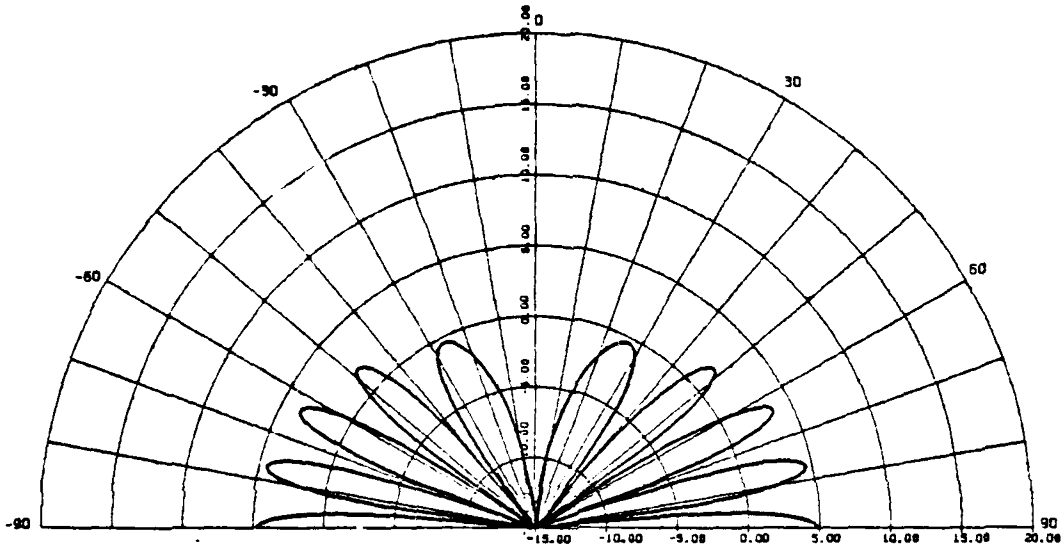
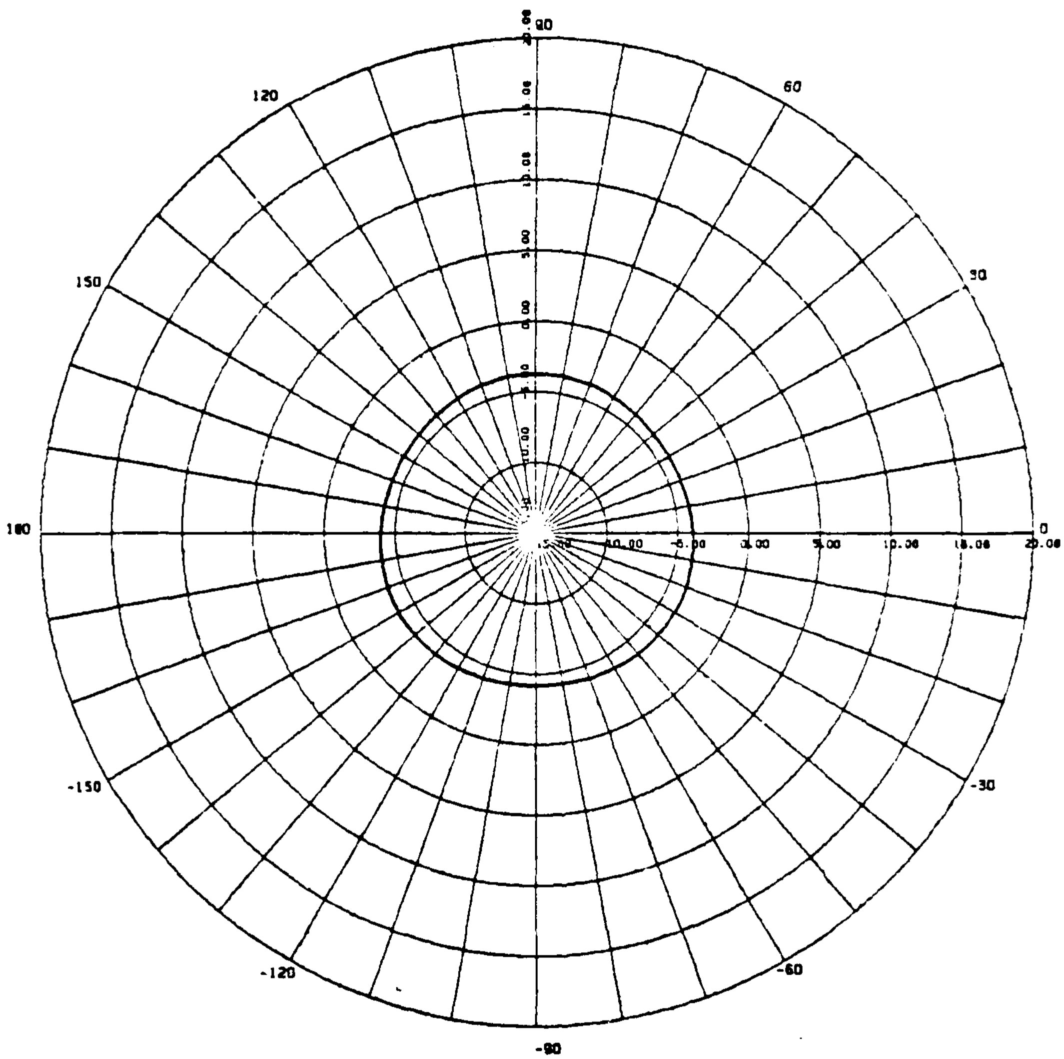
PERFECT GRND/TECH MANUAL CONFIG/75 MHZ



AC-292 / PHI/ THETA=80 (LOADED)

PERFECT GRND / TROOP CONFIG / 75 MHZ



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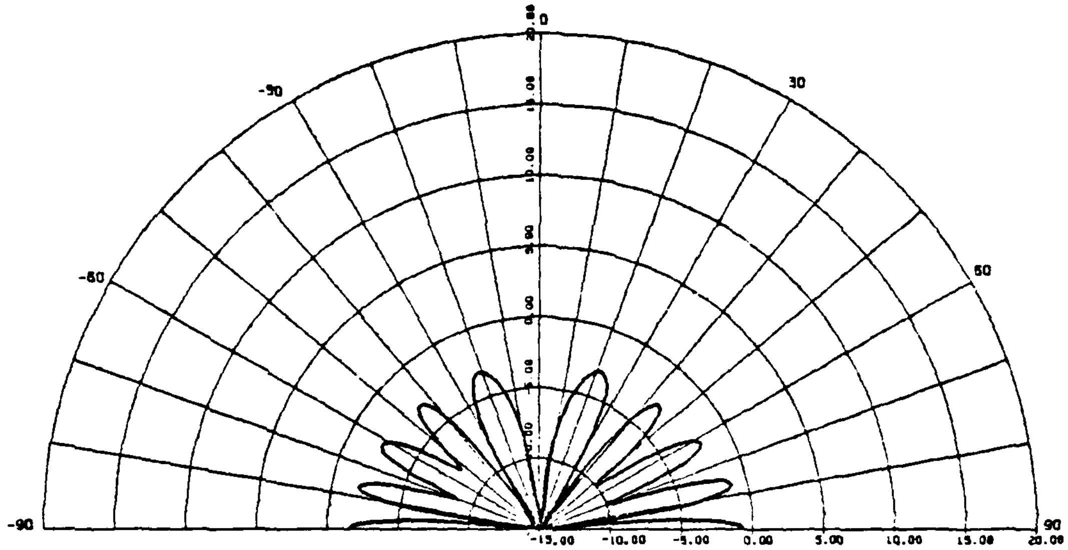
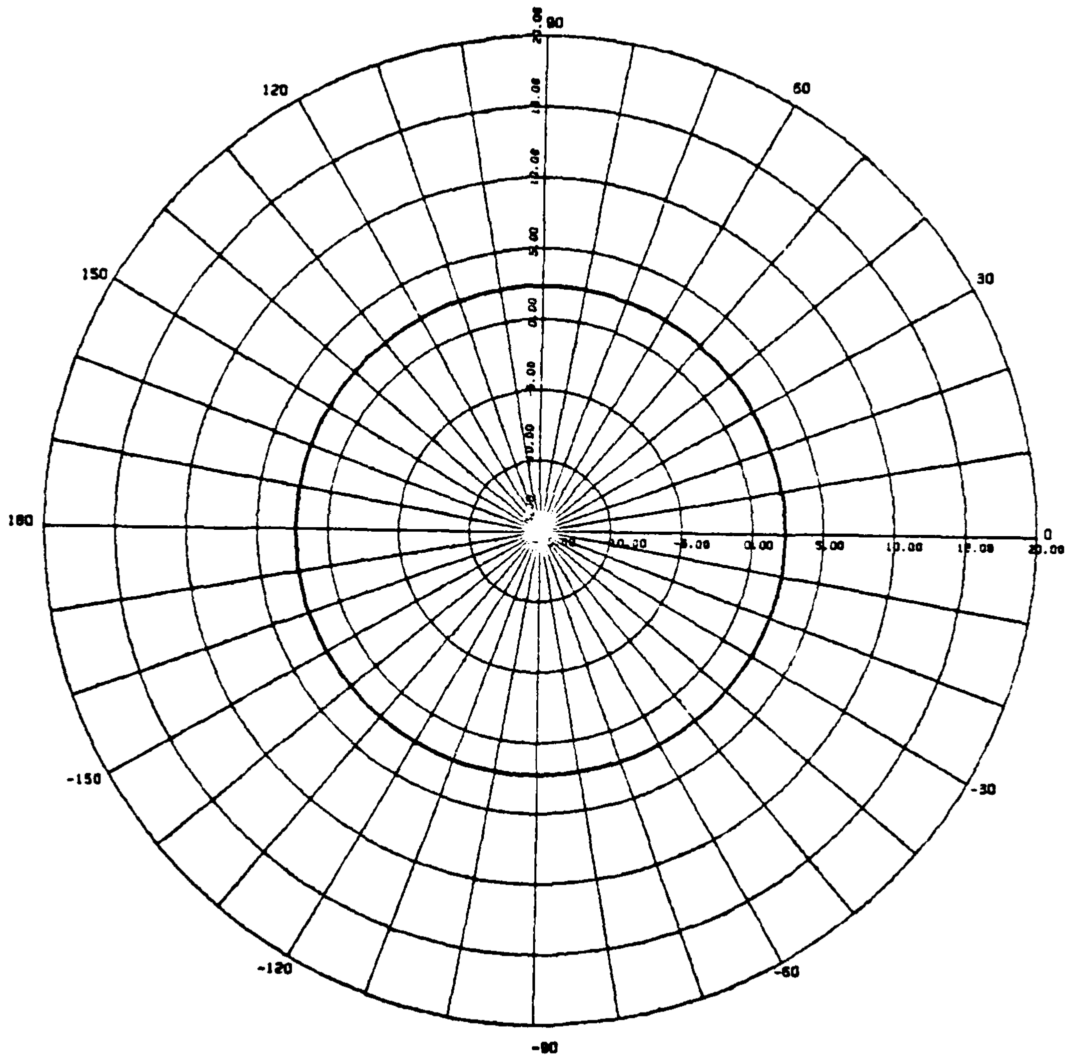
PERFECT GRND / TROOP CONFIG / 75 MHZ



RC-292 / PHI / THETA=80 (LOADED)

WET GRND/TECH MANUAL CONFIG/30 MHZ



AC-292 / THETA / PHI=90 (LOADED)

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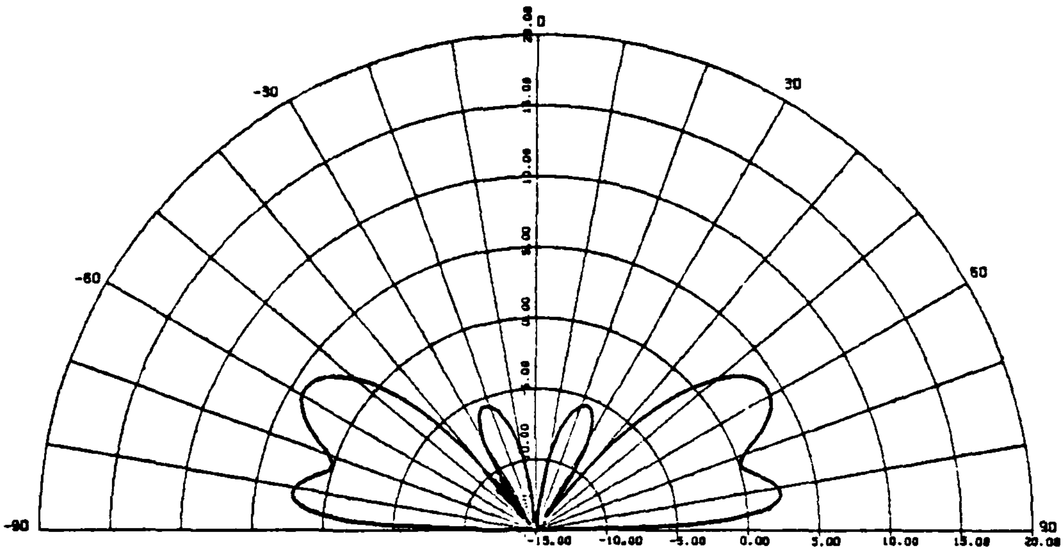

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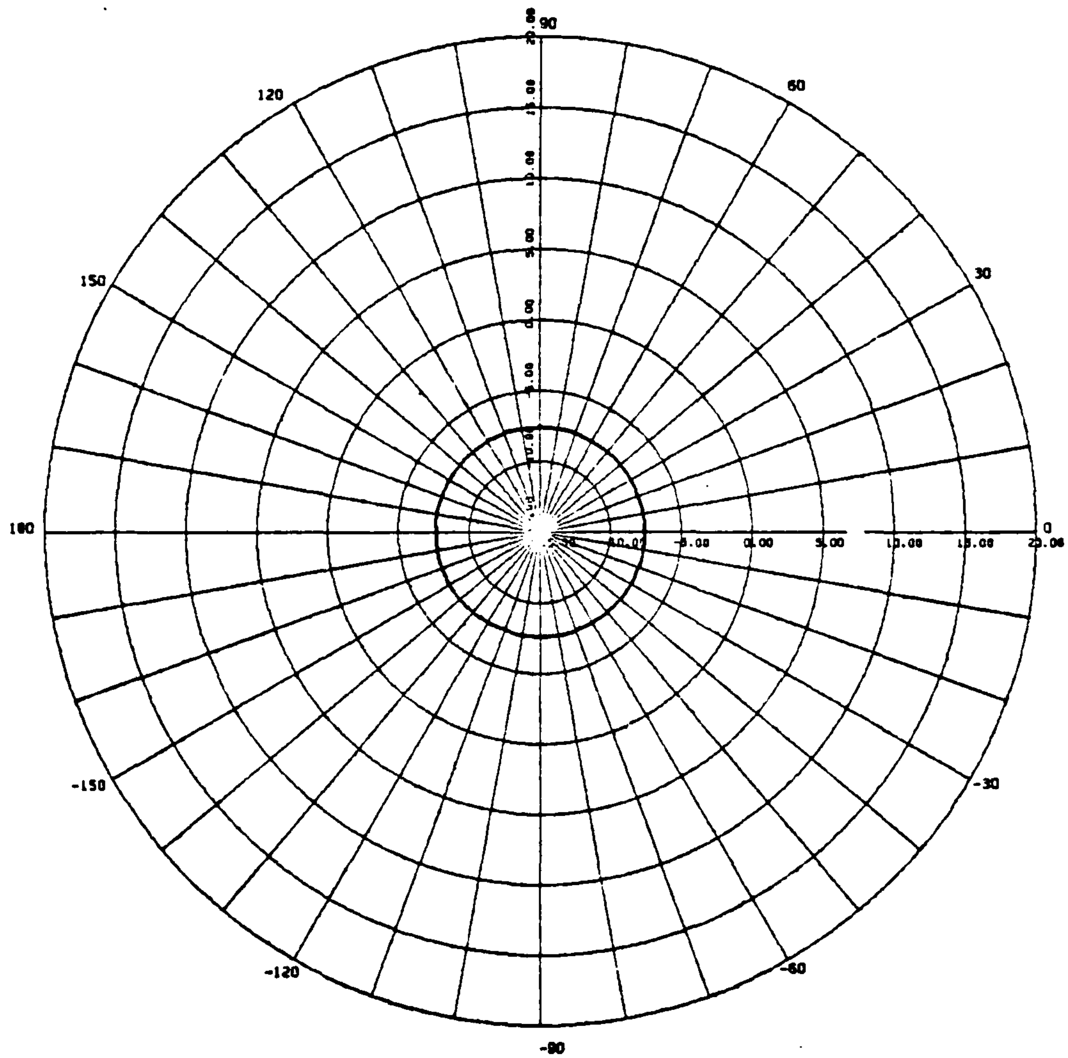

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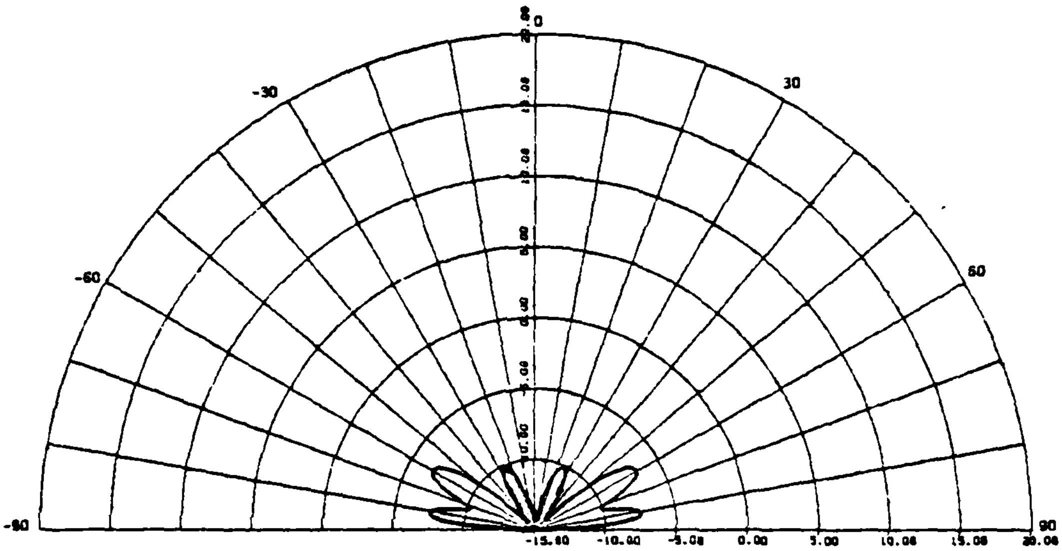
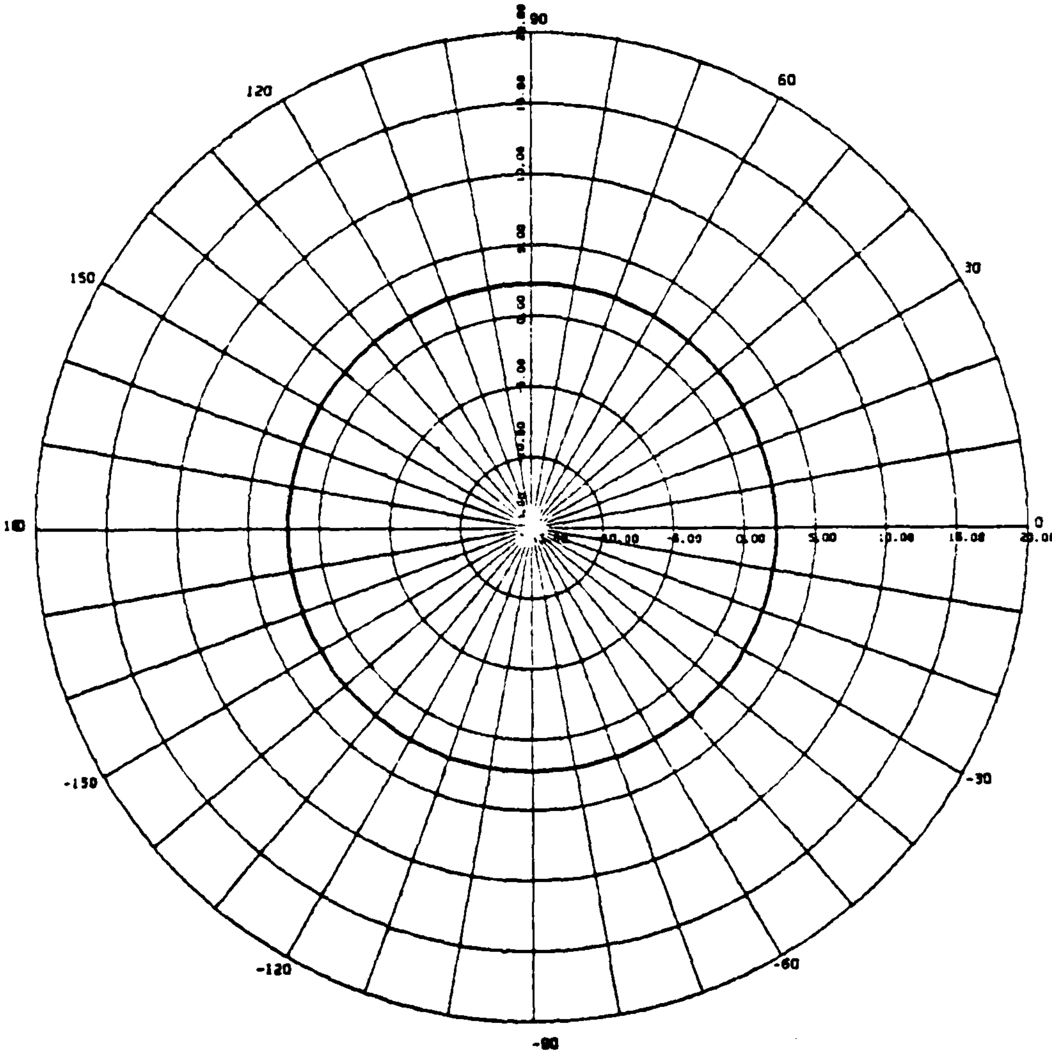


RC-292 / PHI / THETA=80 (LOADED)

WET GRND/TECH MANUAL CONFIG/41 MHZ



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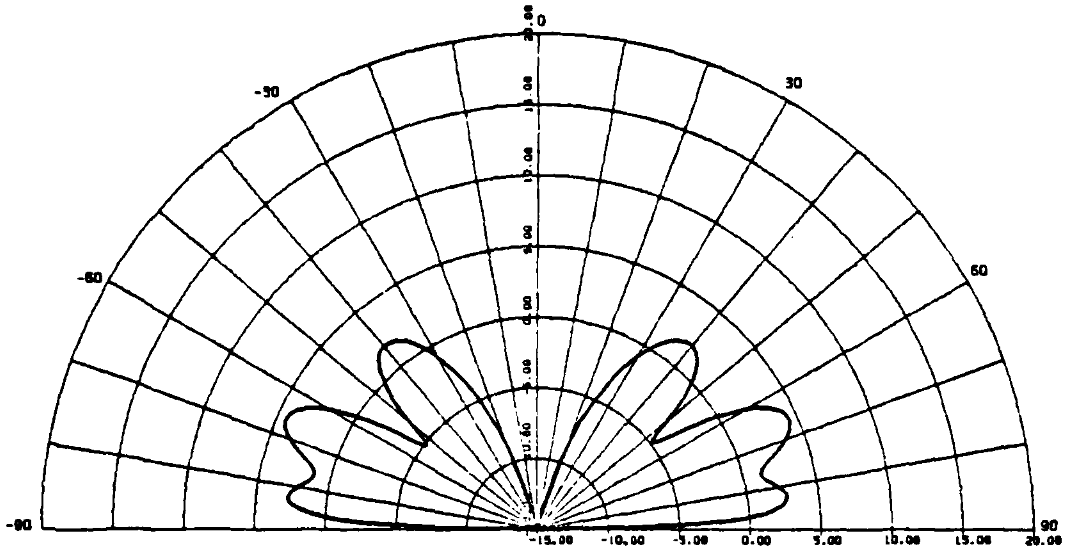

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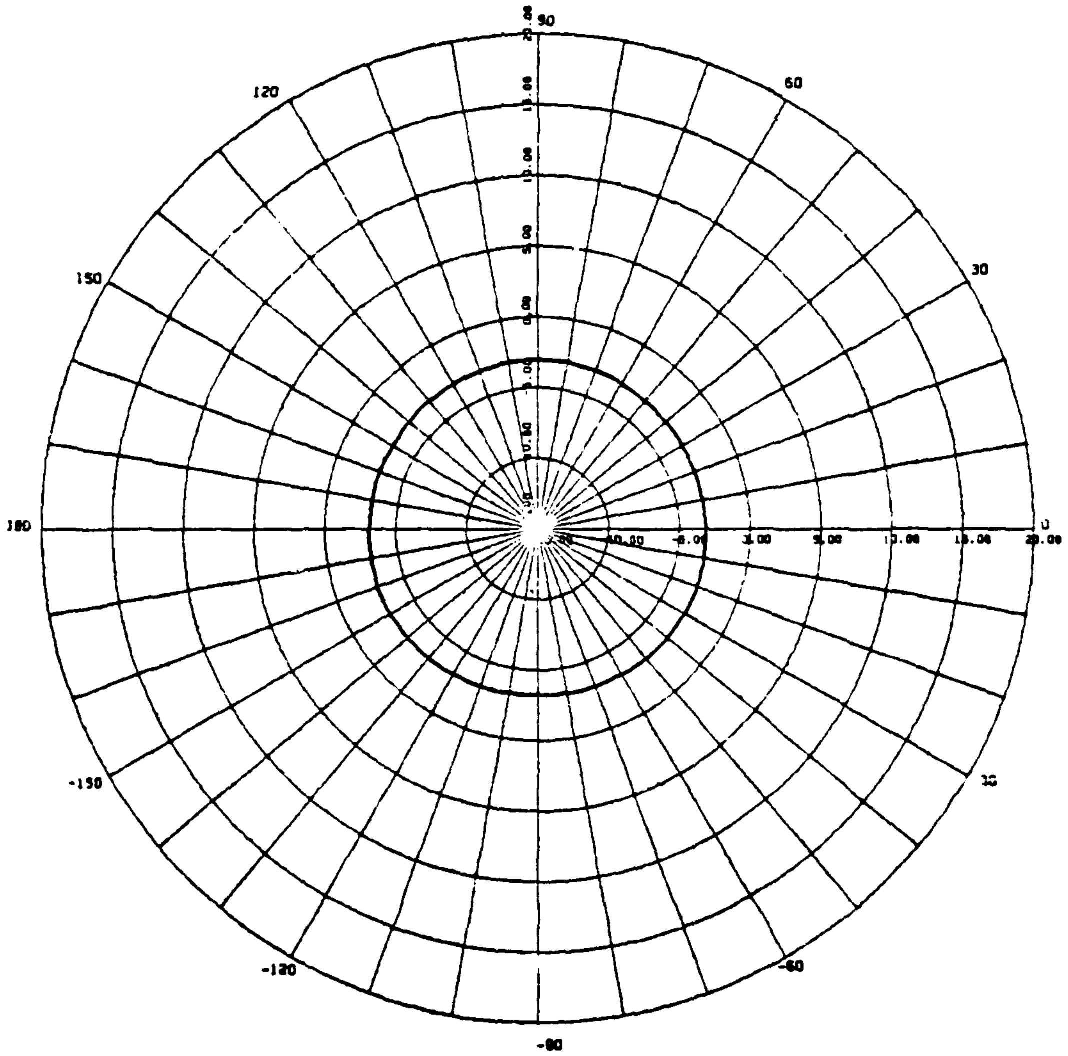
WET GRND/TECH MANUAL CONFIG/50 MHZ



AC-202 / THETA / PHI=30 (LOADED)

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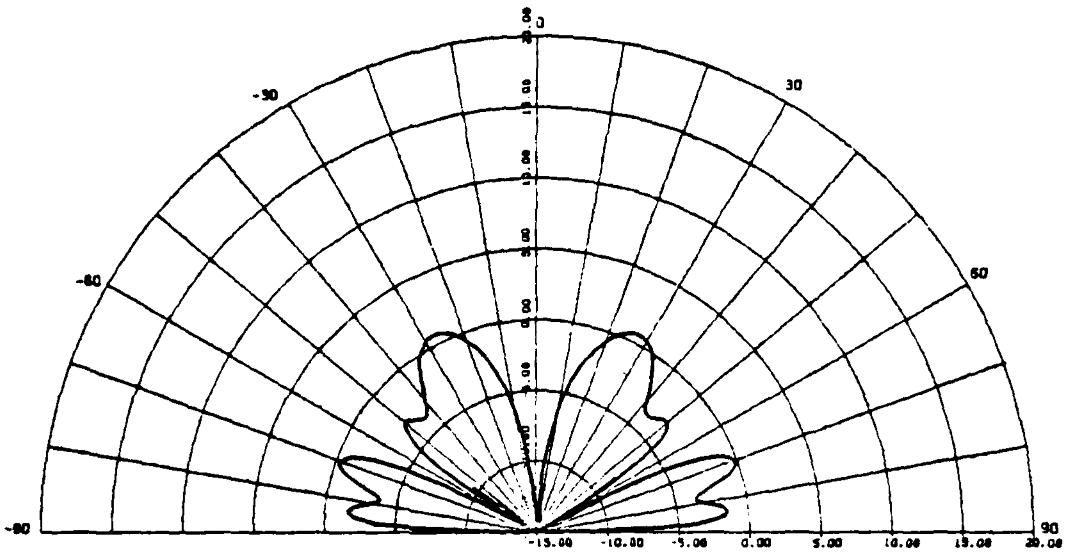
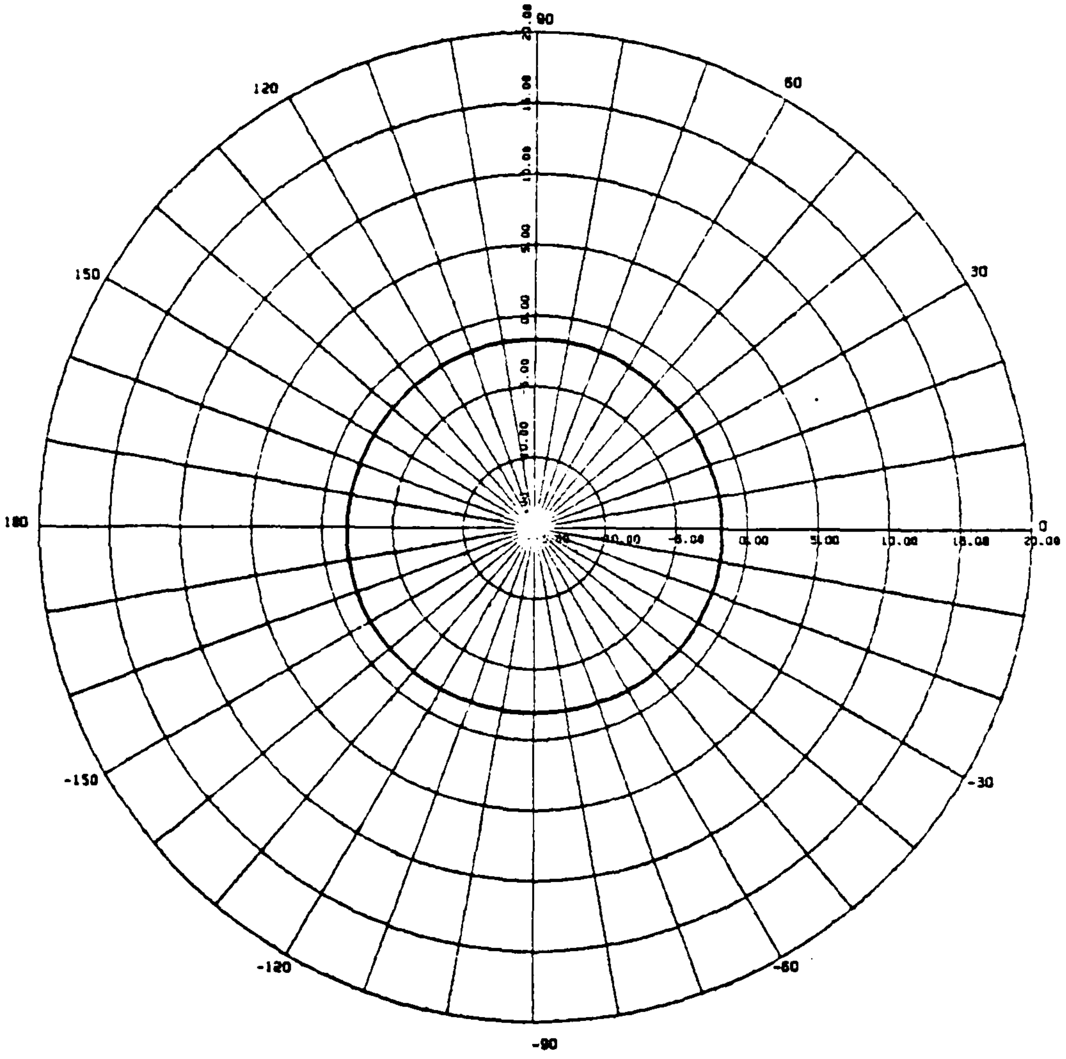


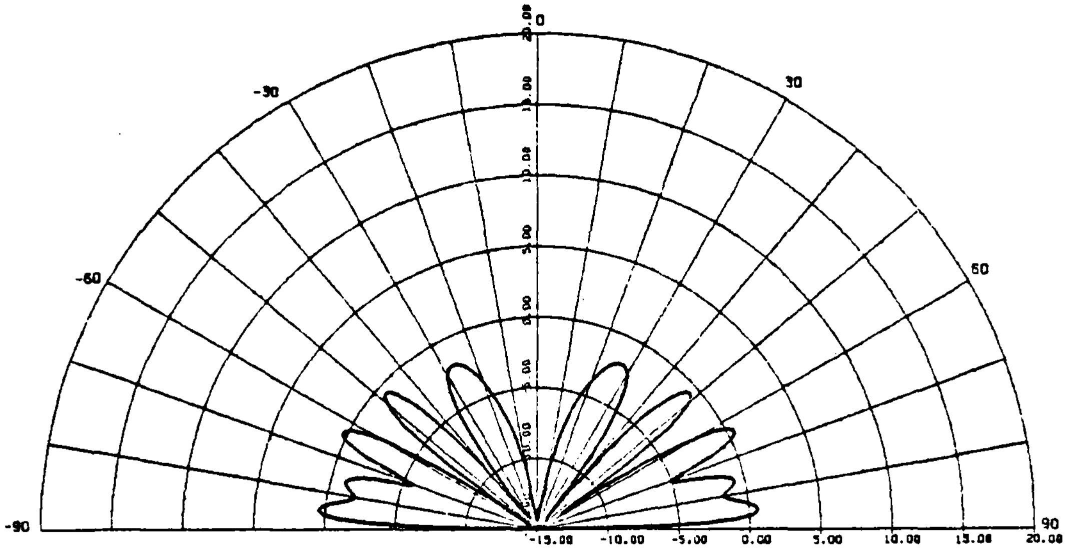
AC-292 / PHI / THETA=80 (LOADED)

WET GRND/TECH MANUAL CONFIG/75 MHZ



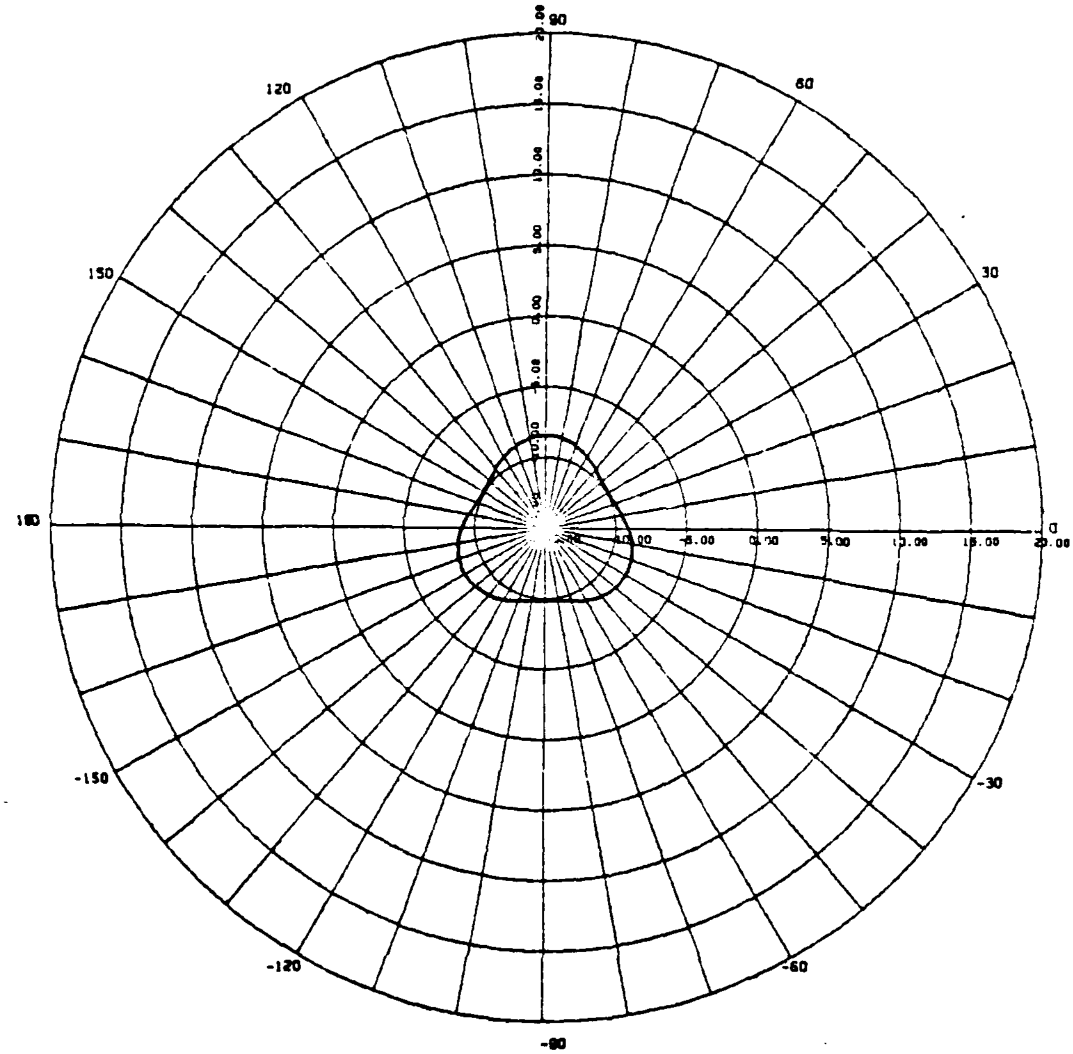
AC-292 , THETA / PHI=90 (LOADED)

WET GRND/TECH MANUAL CONFIG/75 MHZ



RC-292 / PHI / THETA=80 (LOADED)

WET GRND/ TROOP CONFIG/75 MHZ



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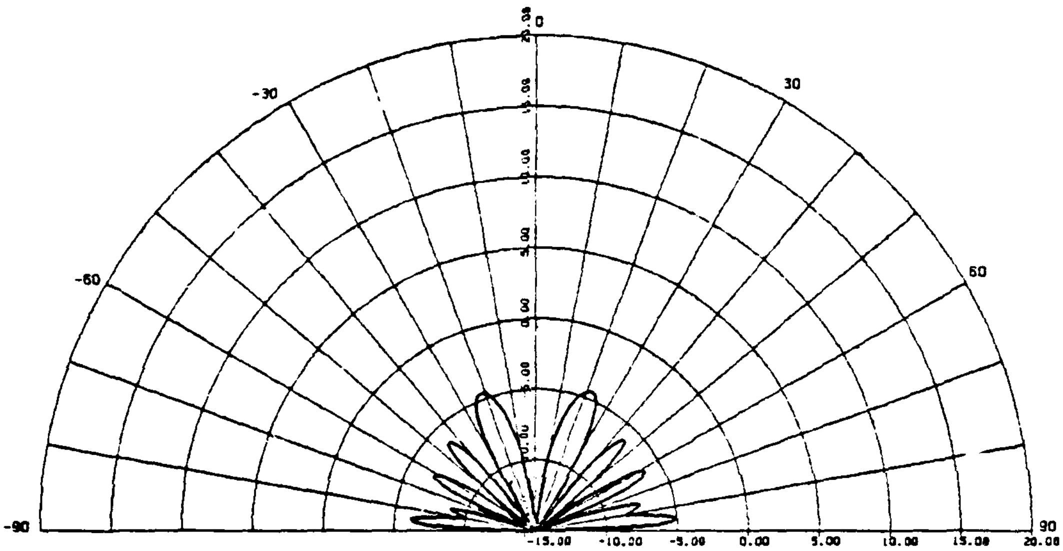
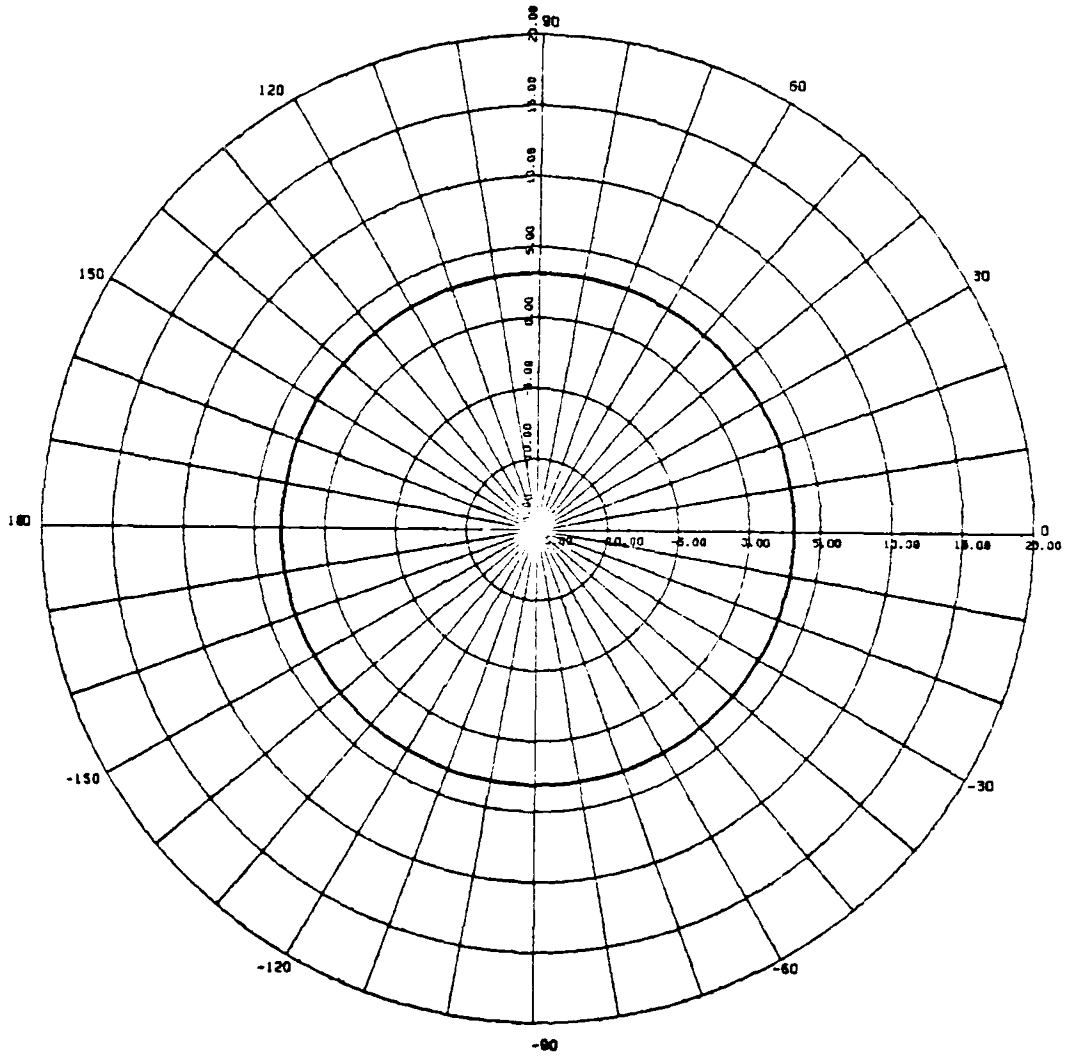
WET GRND/ TROOP CONFIG/75 MHZ



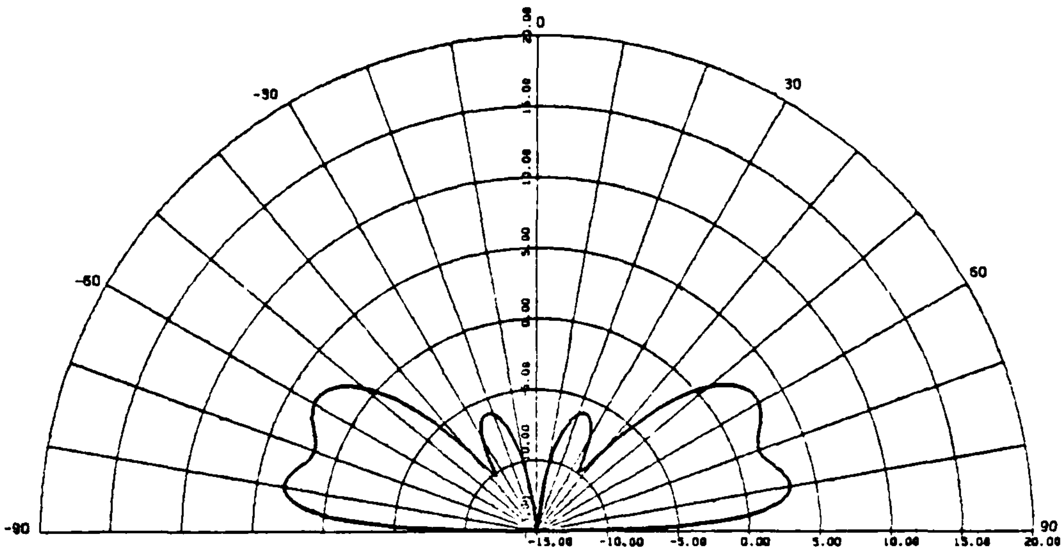
AC-292 / PHI / THETA=80 (LOADED)

PASTORAL/TECH MANUAL CONFIG/30 MHZ



AC-292 / THETA / PHI=90 (LOADED)

PASTORAL/TECH MANUAL CONFIG/30 MHZ



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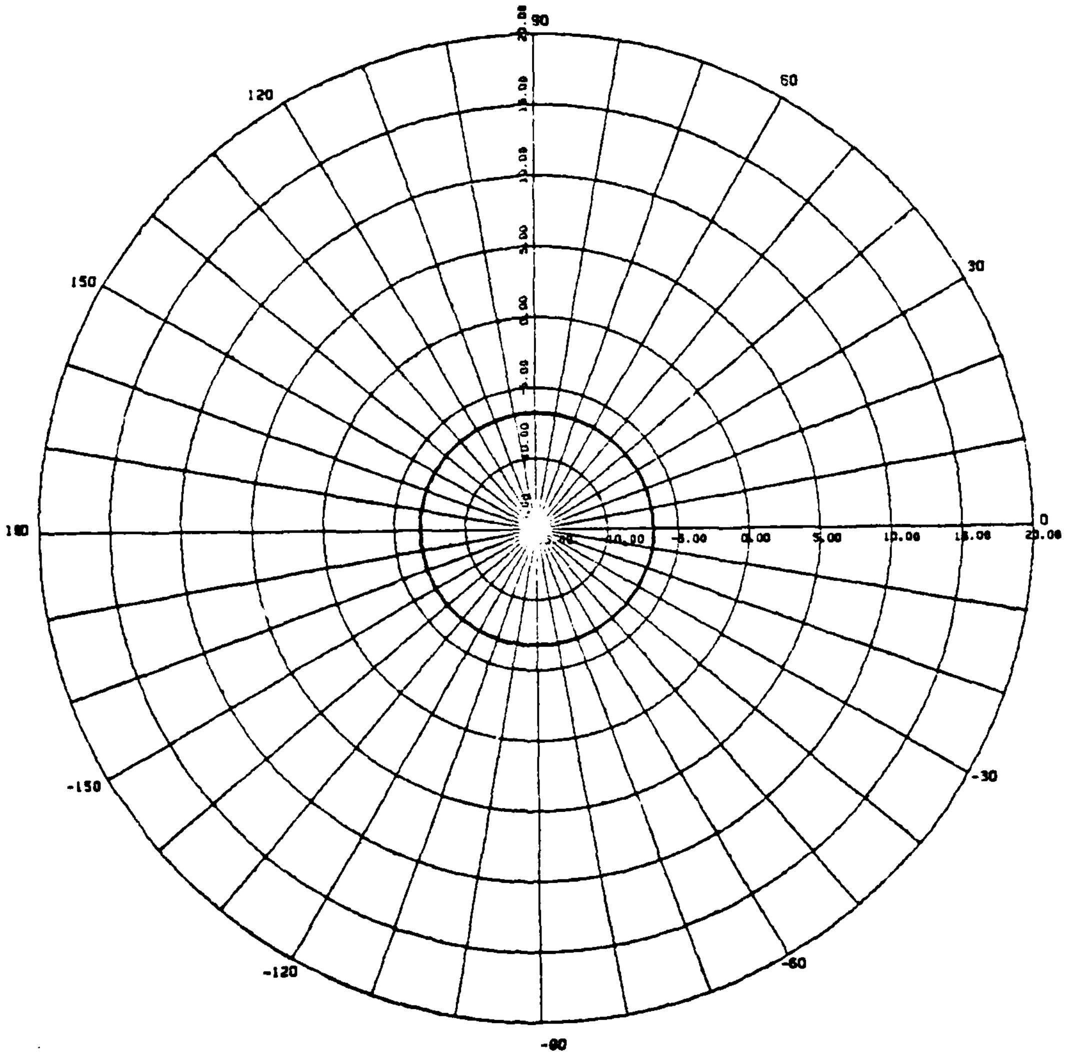
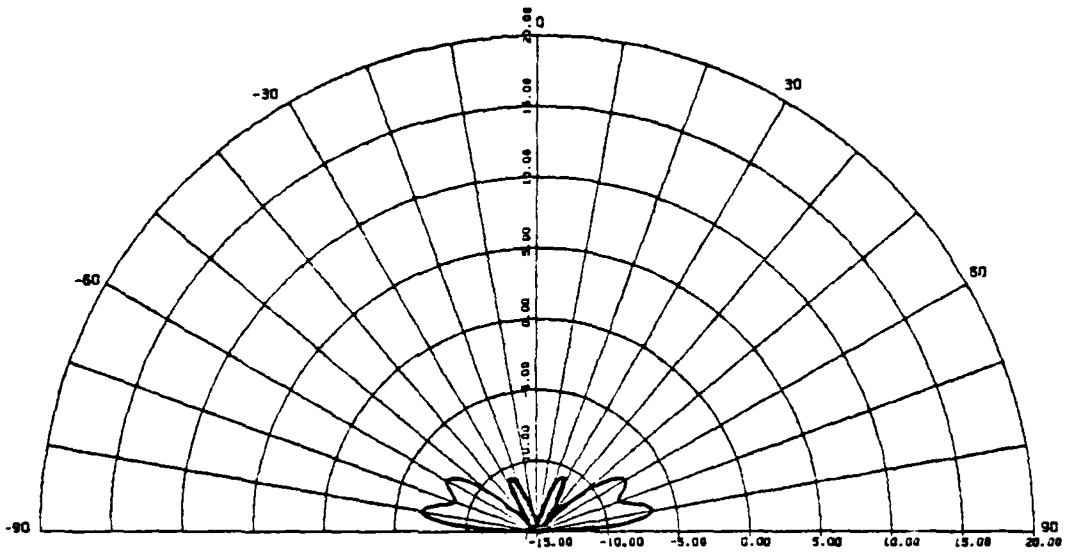
PASTORAL/ TROOP CONFIG/30 MHZ



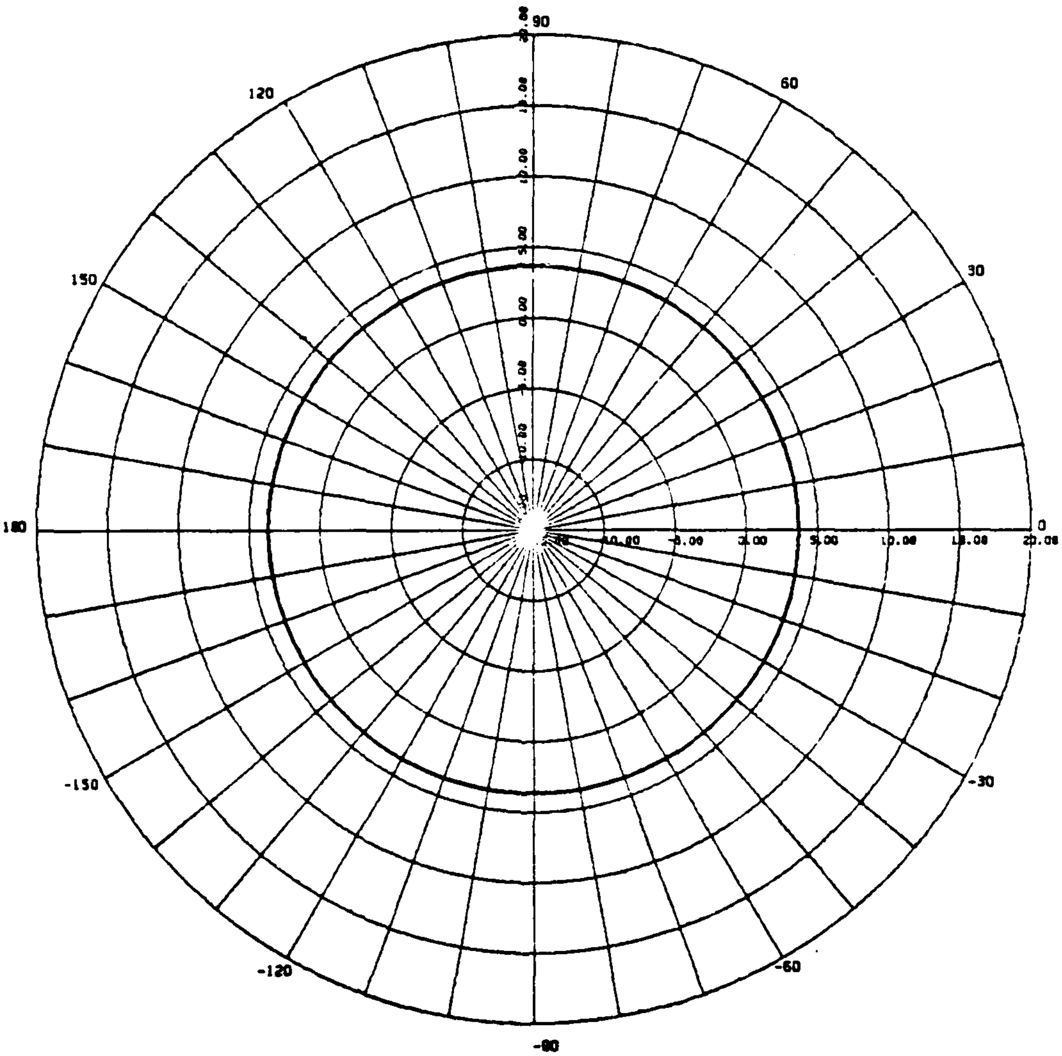
RC-292 / THETA / PHI=90 (LOADED)

PASTORAL/ TROOP CONFIG/30 MHZ



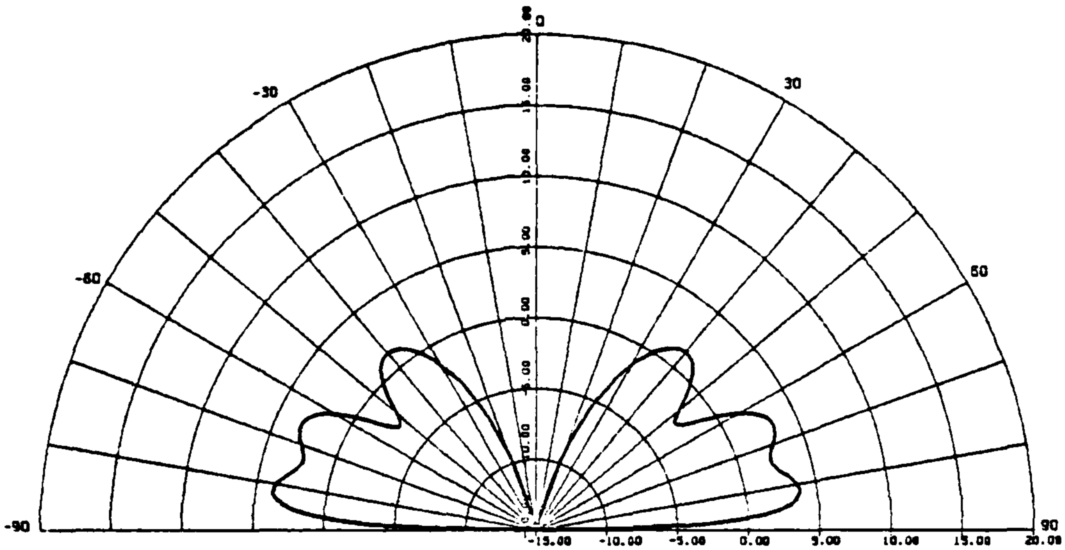
AC-292 / PHI / THETA=80 (LOADED)

PASTORAL/TECH MANUAL CONFIG/41 MHZ



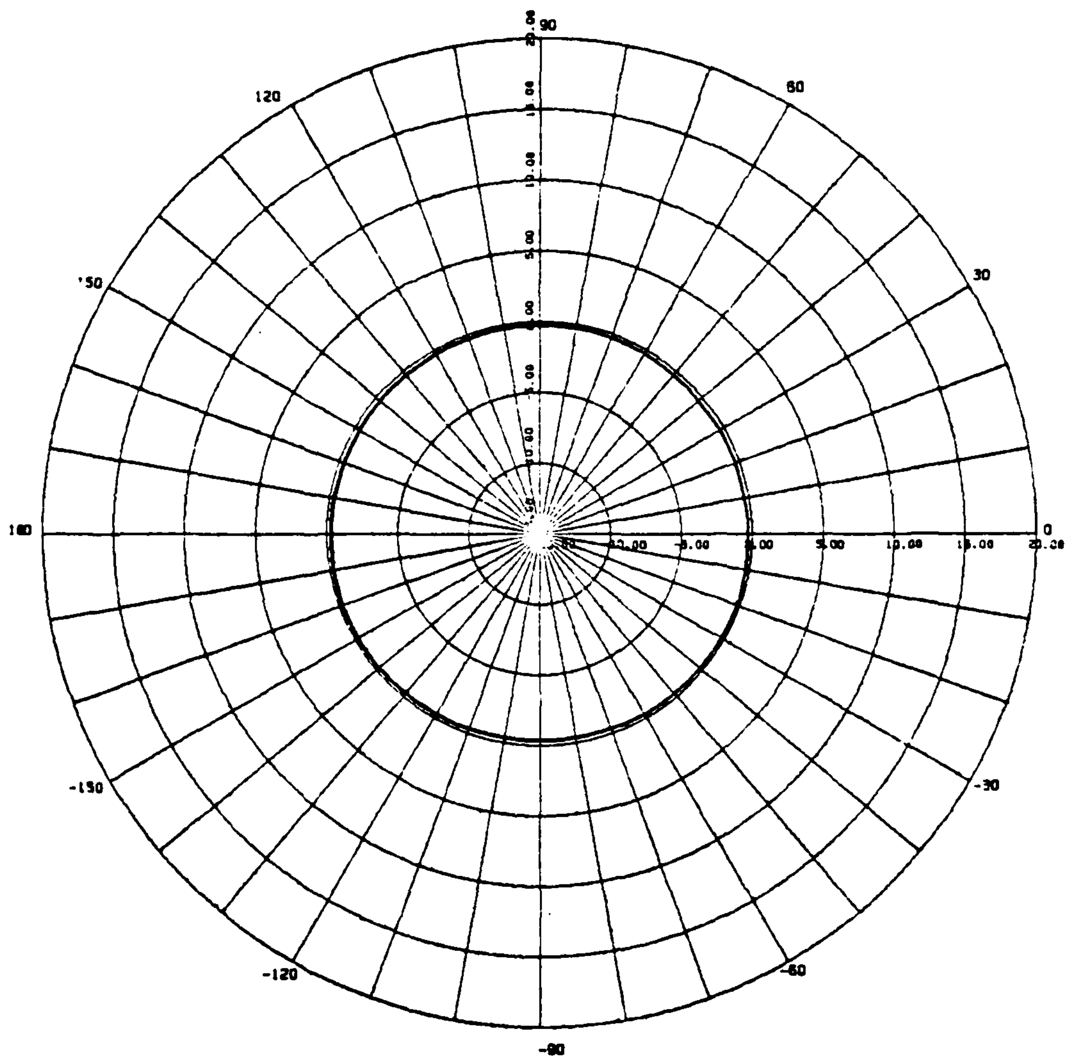
AC-292 / THETA / PHI=90 (LOADED)

PASTORAL/TECH MANUAL CONFIG/41 MHZ



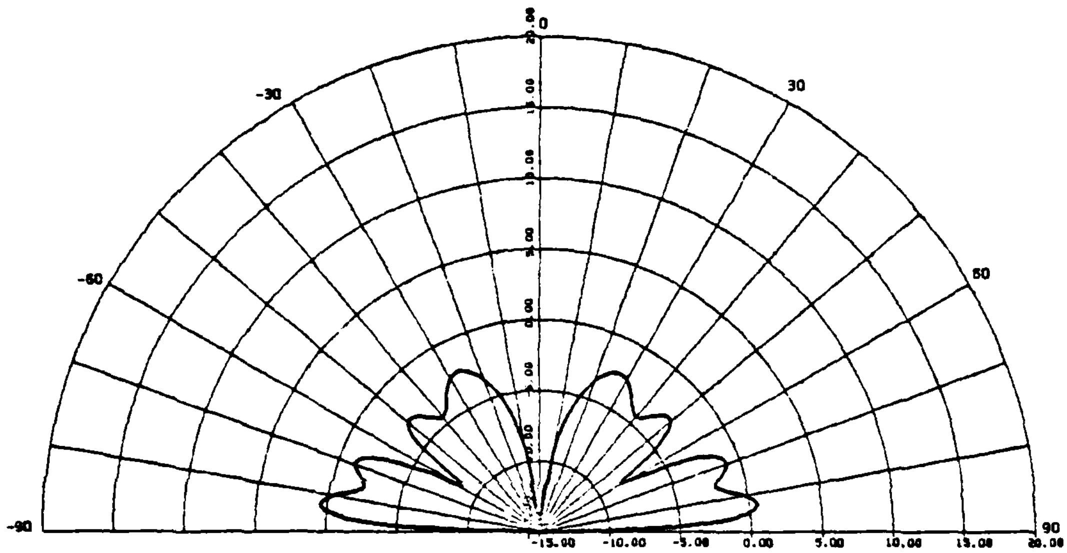
AC-232 / PHI / THETA=60 (LOADED)

PASTORAL/TECH MANUAL CONFIG/50 MHZ



AC-292 / THETA / PHI=90 (LOADED)

PASTORAL/TECH MANUAL CONFIG/50 MHZ



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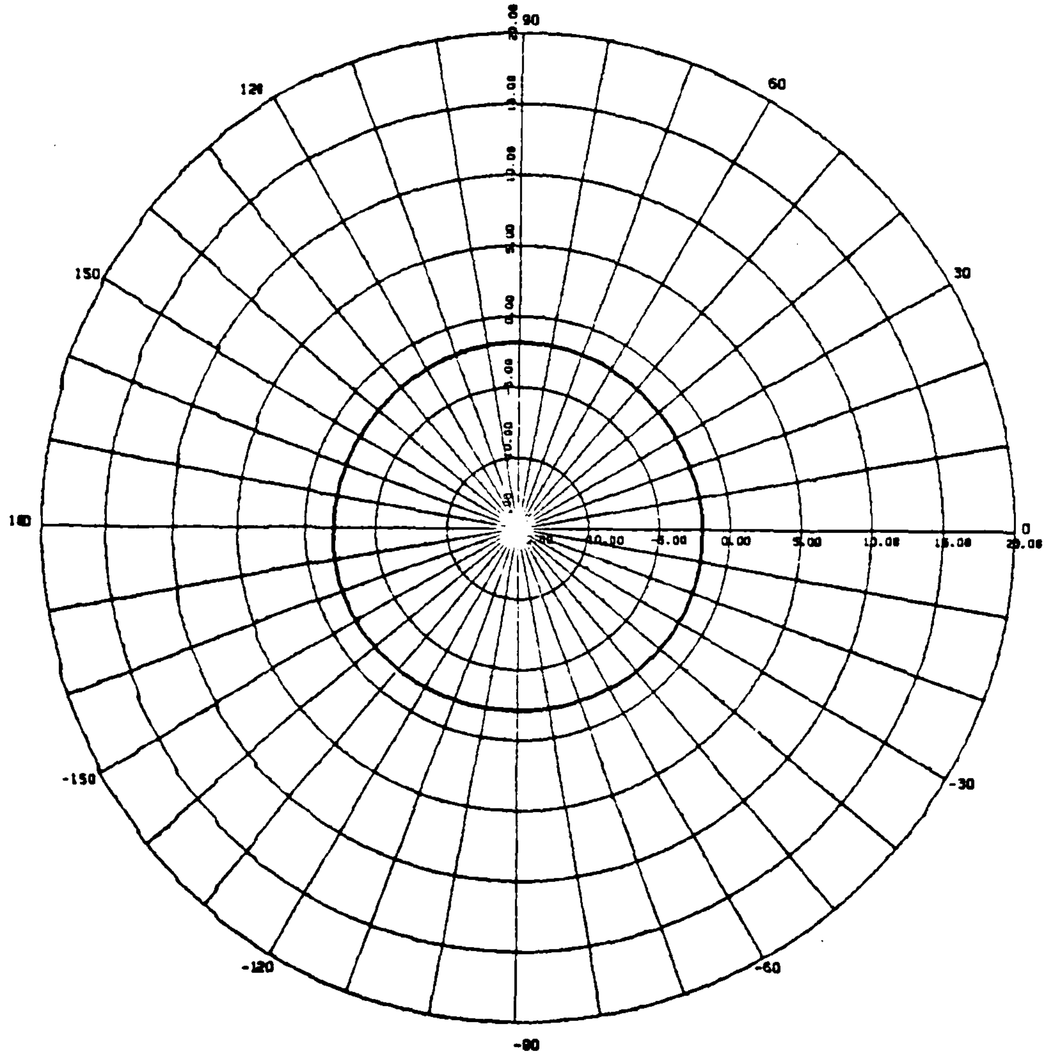
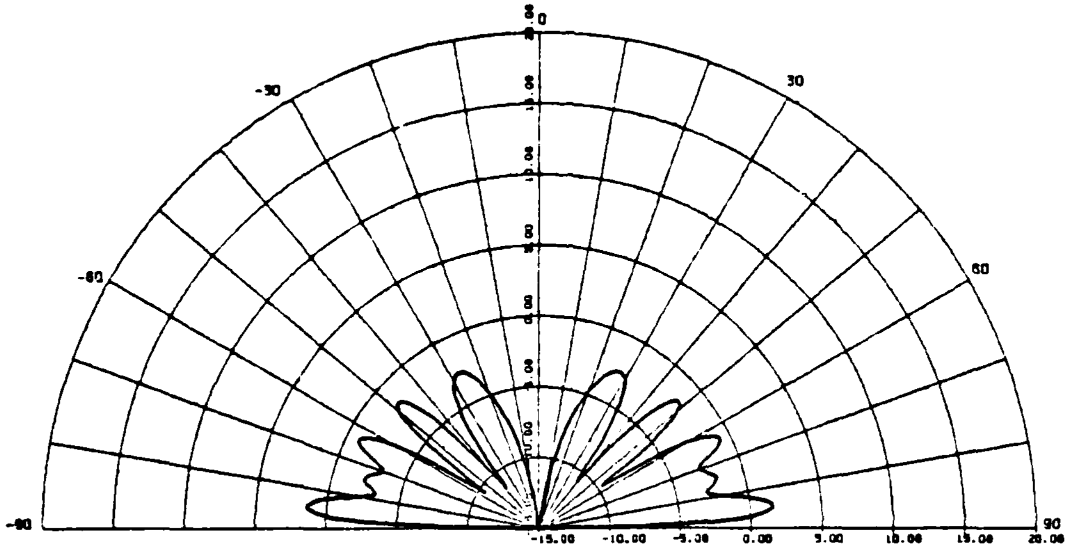


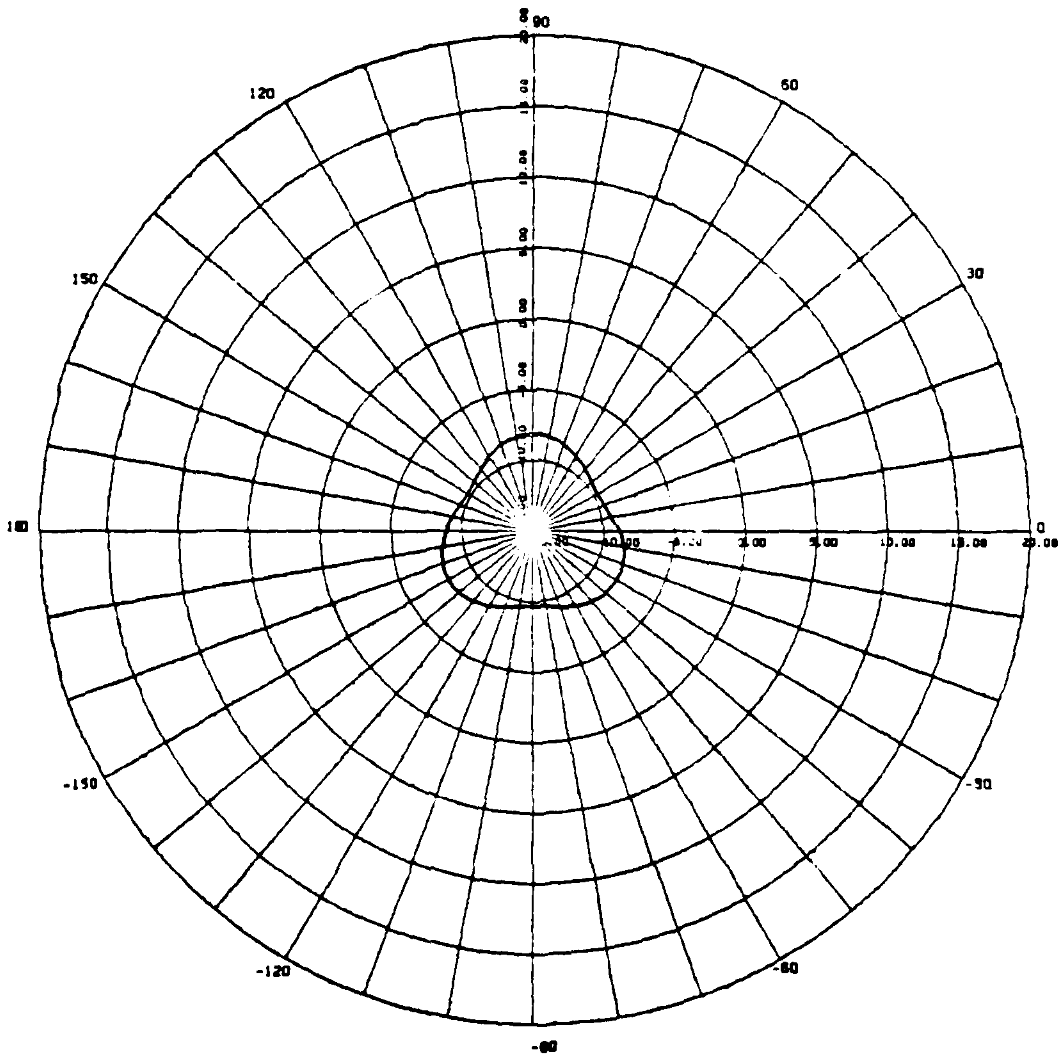
AC-292 / THETA / PHI=90 (LOADED)

PASTORAL/TECH MANUAL CONFIG/75 MHZ



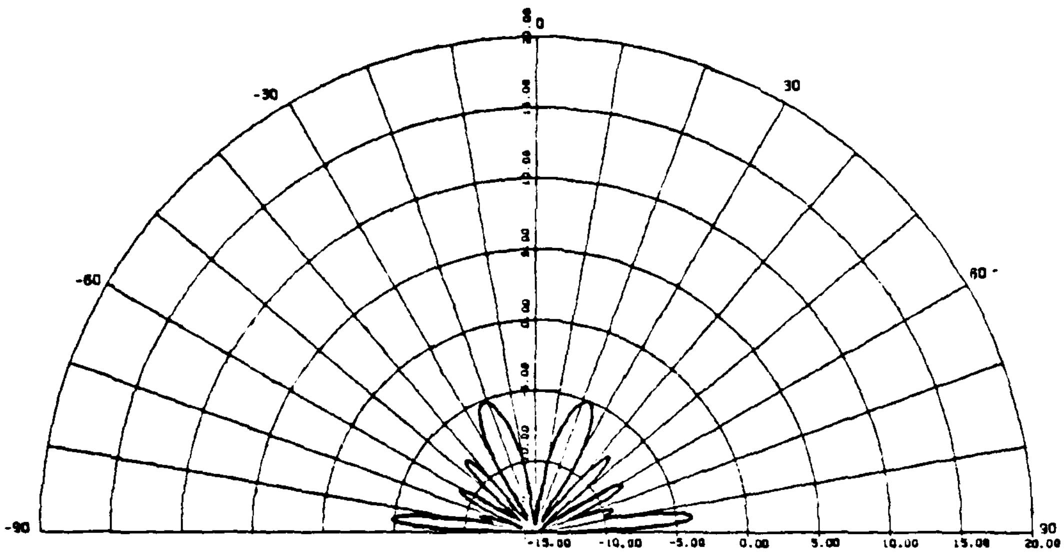
AC-292 / PHI / THETA=80 (LOADED)

PASTORAL/ TROOP CONFIG/75 MHZ



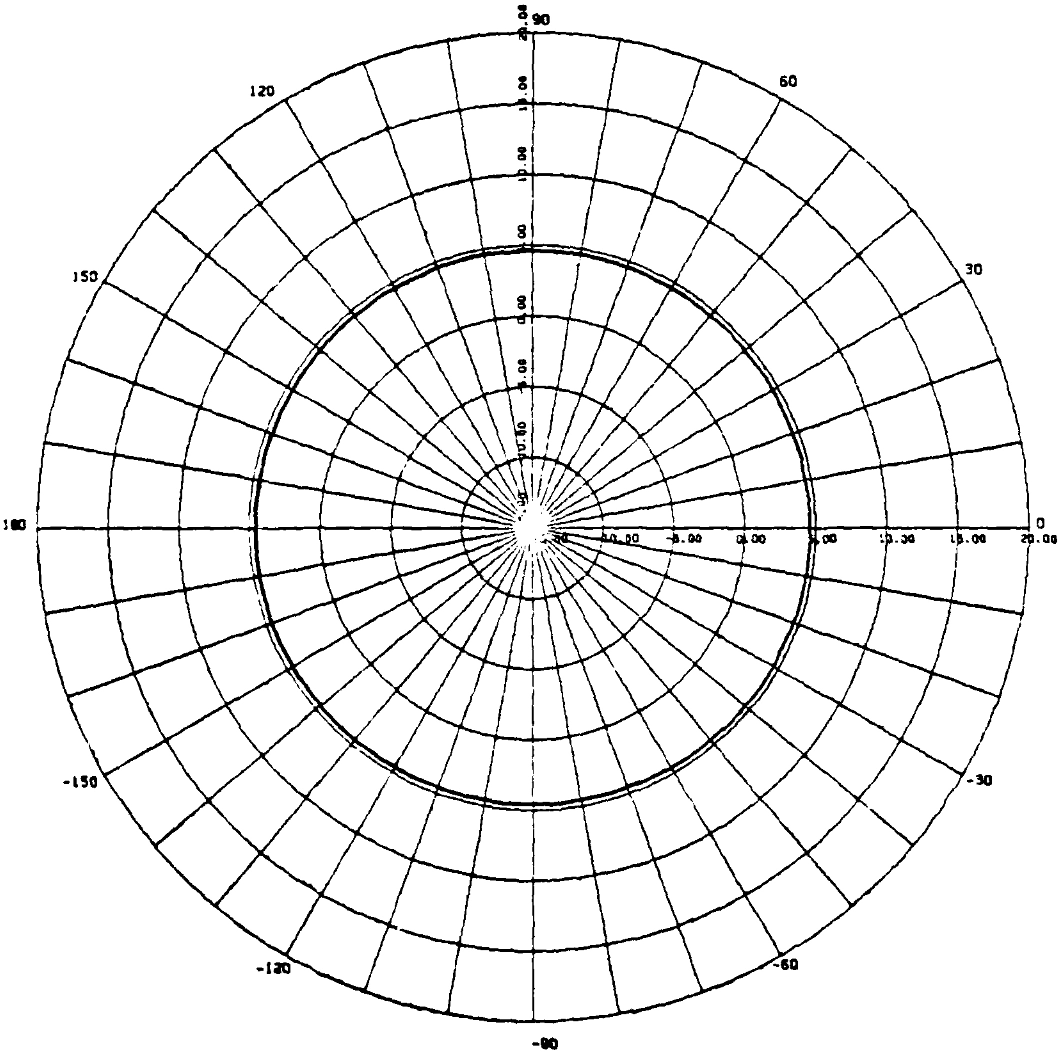
RC-292 / THETA / PHI=90 (LOADED)

PASTORAL/ TROOP CONFIG/75 MHZ



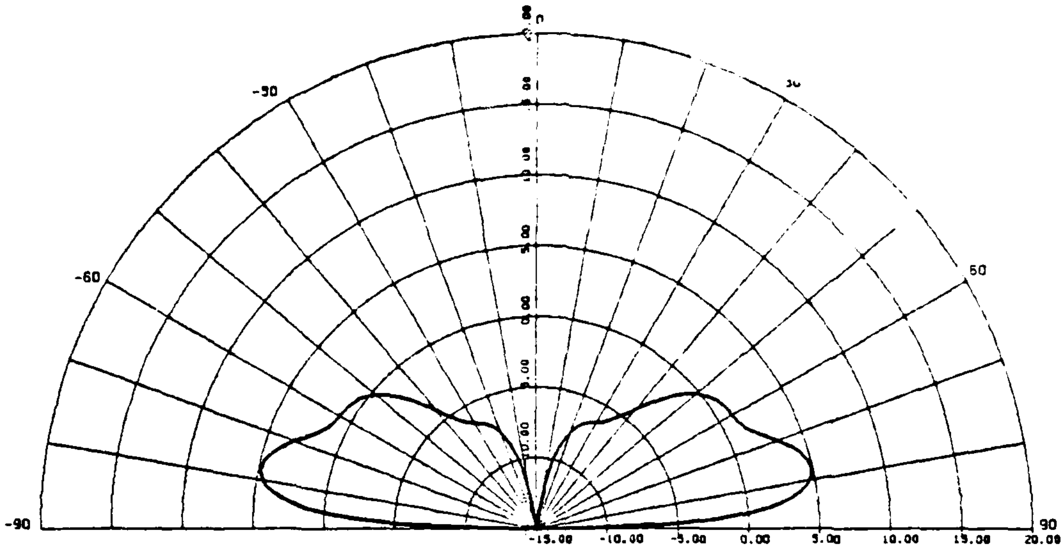
AC-292 / PHI / THETA=80 (LOADED)

SNOW /TECH MANUAL CONFIG/30 MHZ



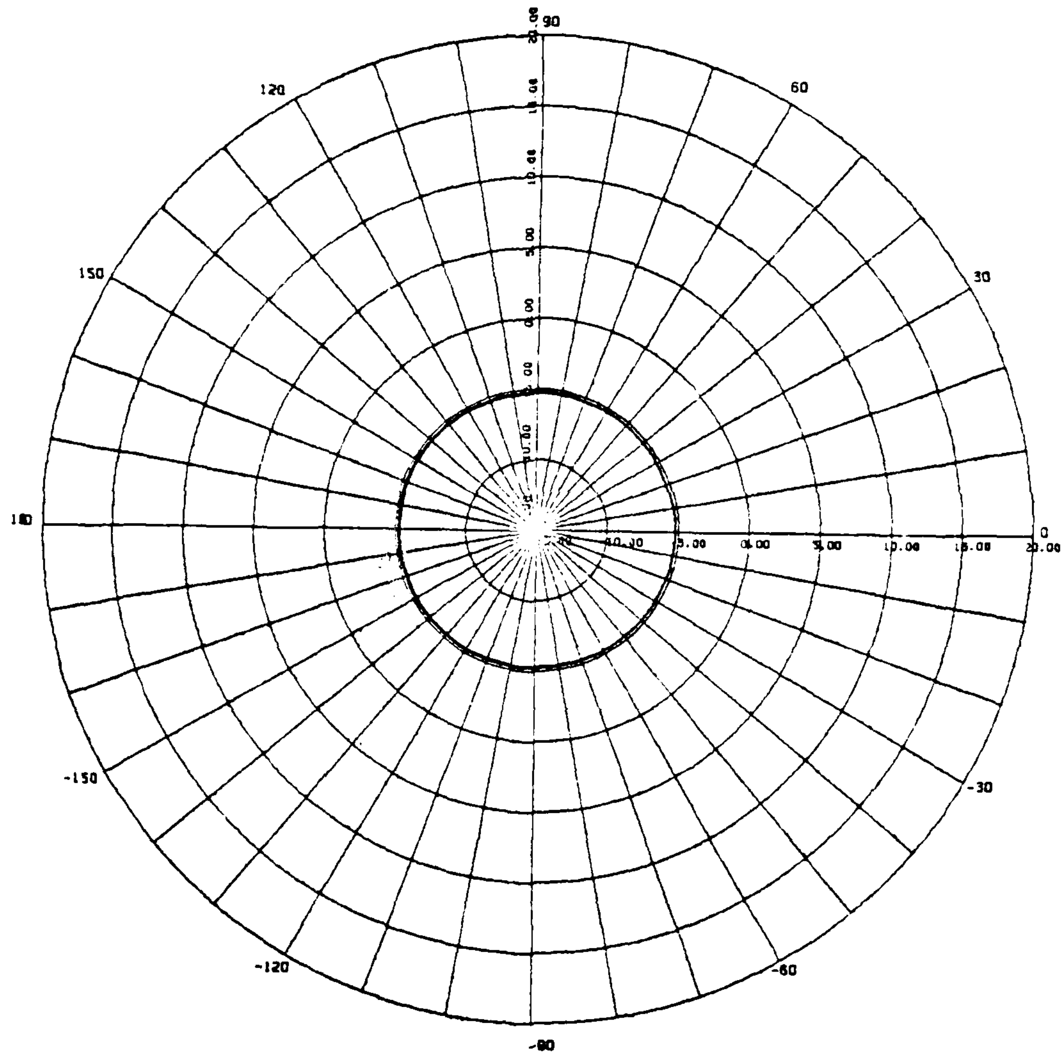
AC-292 / THETA / PHI=90 (LOADED)

SNOW /TECH MANUAL CONFIG/30 MHZ



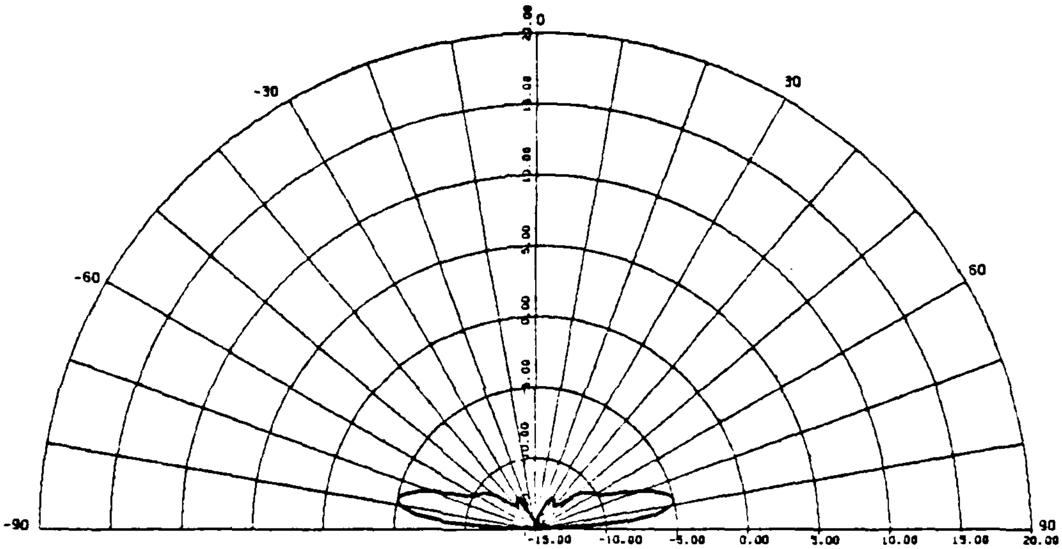
AC-292 / PHI / THETA=80 (LOADED)

SNOW / TROOP CONFIG/30 MHZ



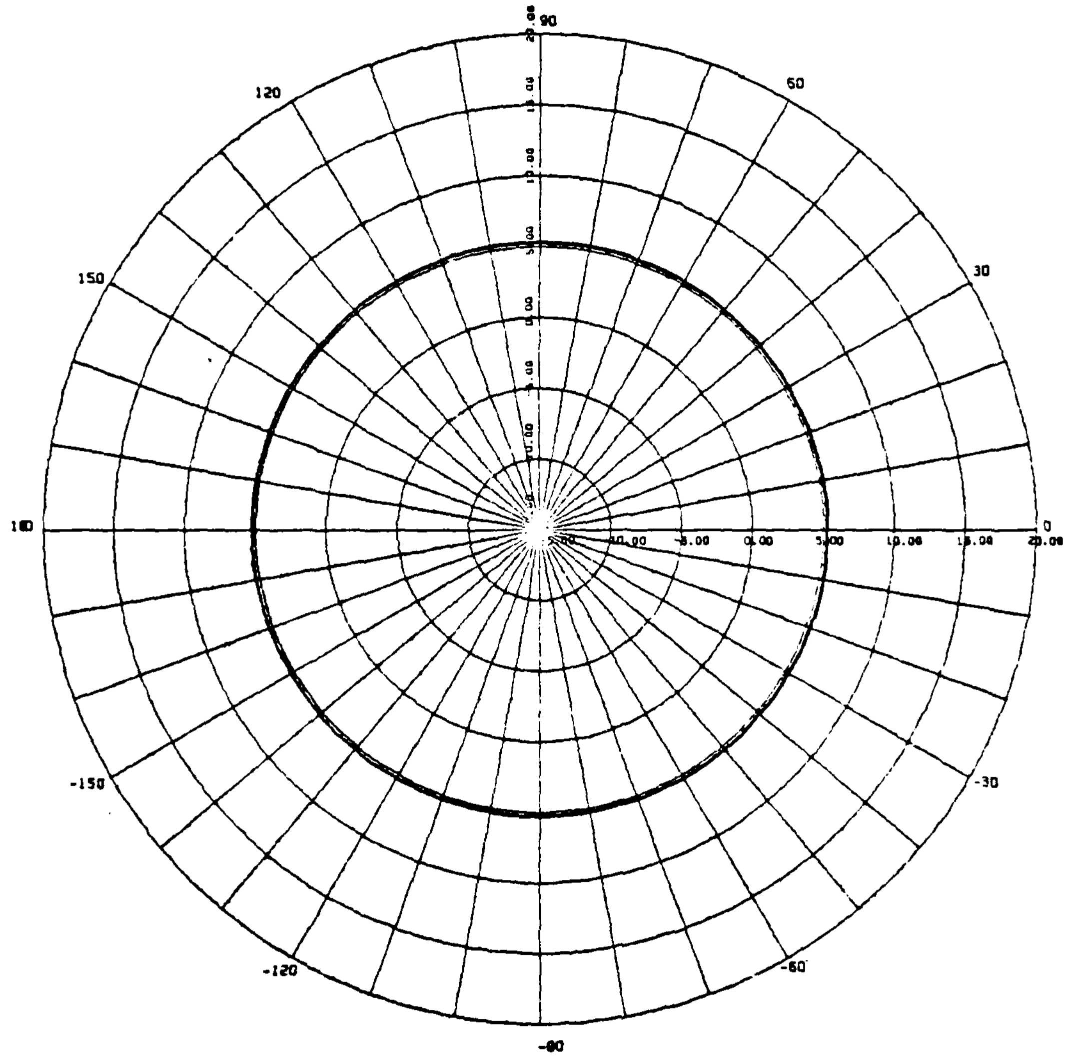
AC-292 / THETA / PHI=90 (LOADED)

SNOW / TROOP CONFIG/30 MHZ



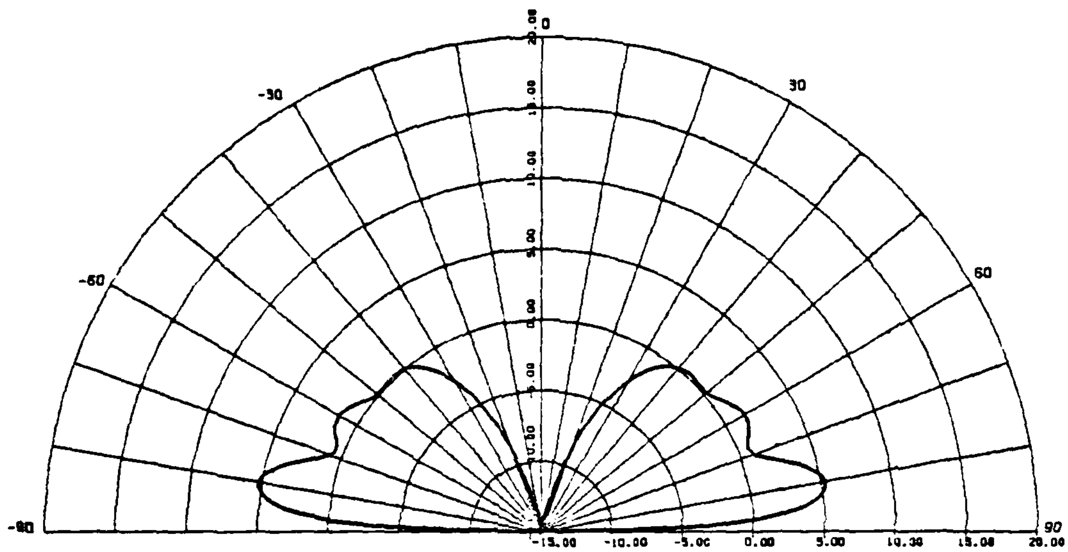
AC-292 / PHI / THETA=80 (LOADED)

SNOW /TECH MANUAL CONFIG/41 MHZ



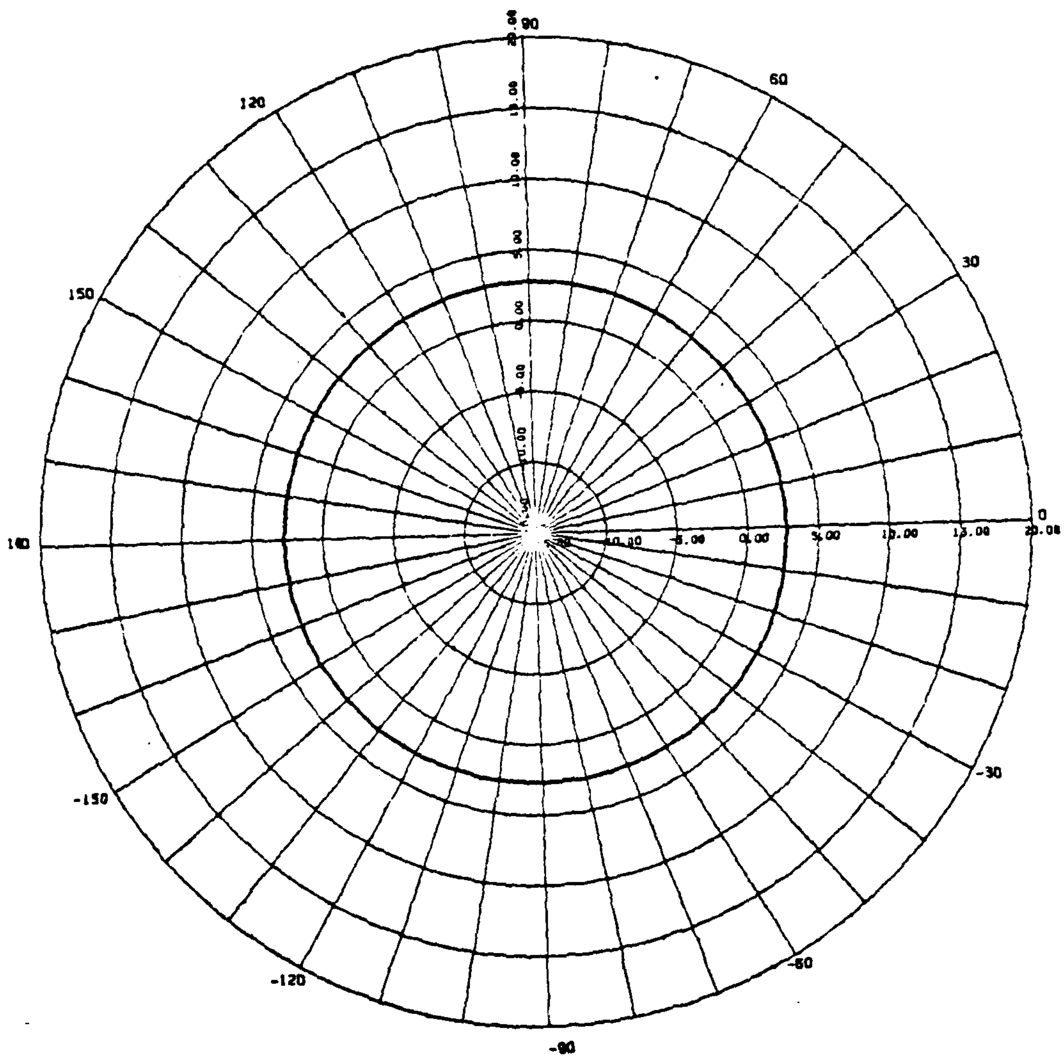
AC-292 / THETA / PHI=90 (LOADED)

SNOW /TECH MANUAL CONFIG/41 MHZ



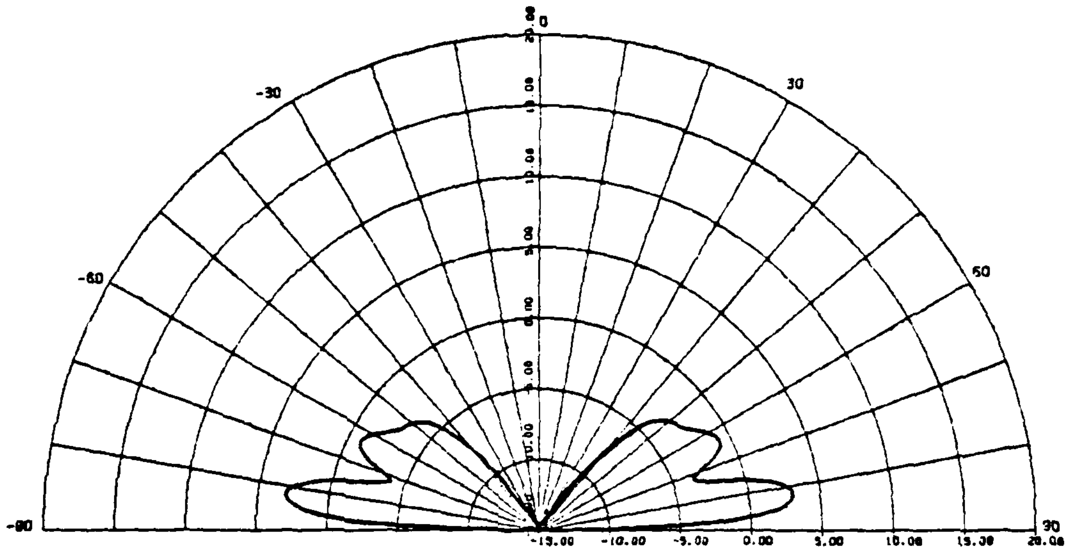
RC-292 / PHI / THETA=80 (LOADED)

SNOW /TECH MANUAL CONFIG/50 MHZ



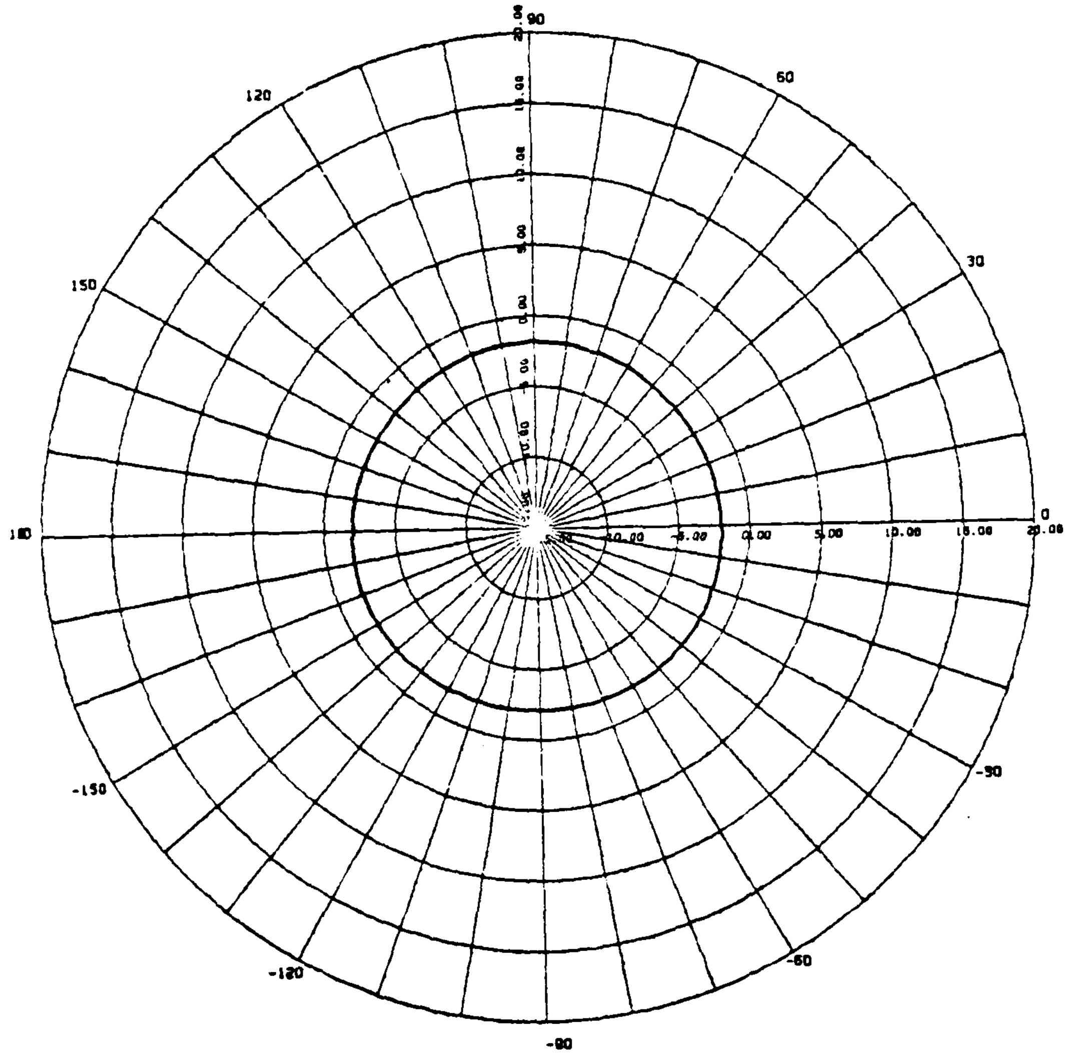
RC-292 / THETA / PHI=90 (LOADED)

SNOW /TECH MANUAL CONFIG/50 MHZ



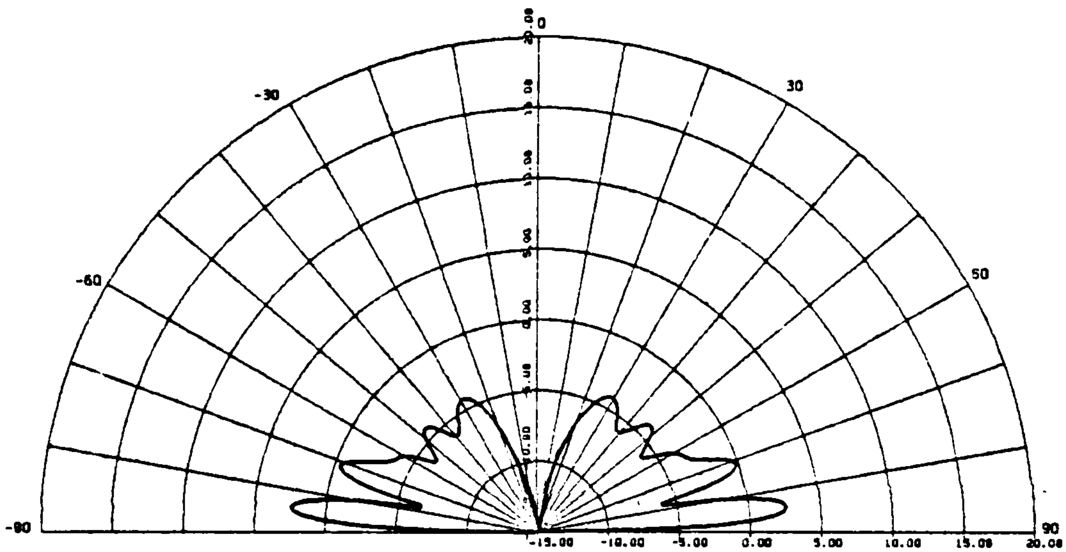
AC-292 / PHI / THETA=80 (LOADED)

SNOW /TECH MANUAL CONFIG/75 MHZ



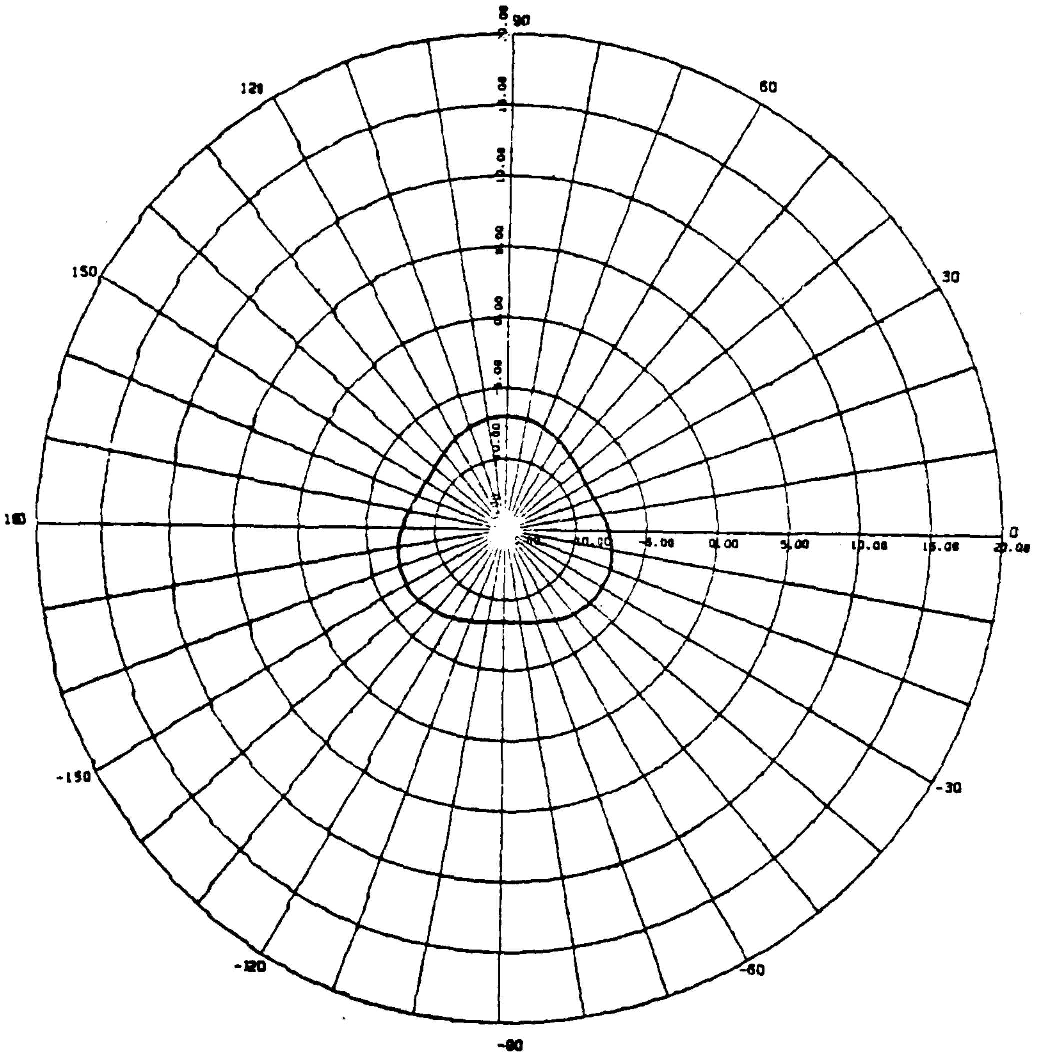
AC-292 / THETA / PHI=90 (LOADED)

SNOW /TECH MANUAL CONFIG/75 MHZ



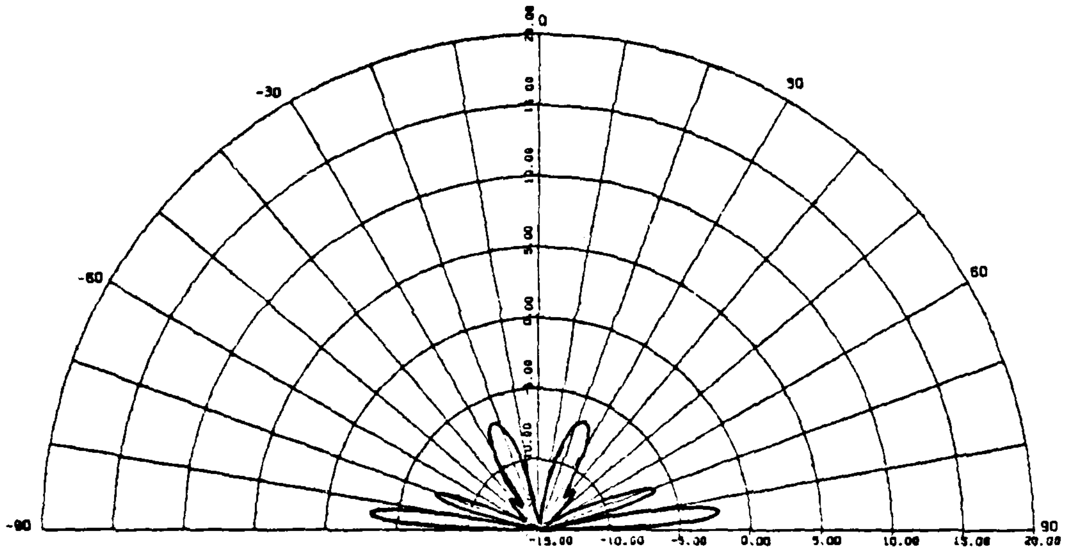
AC-292 / PHI / THETA=80 (LOADED)

SNOW / TROOP CONFIG/75 MHZ



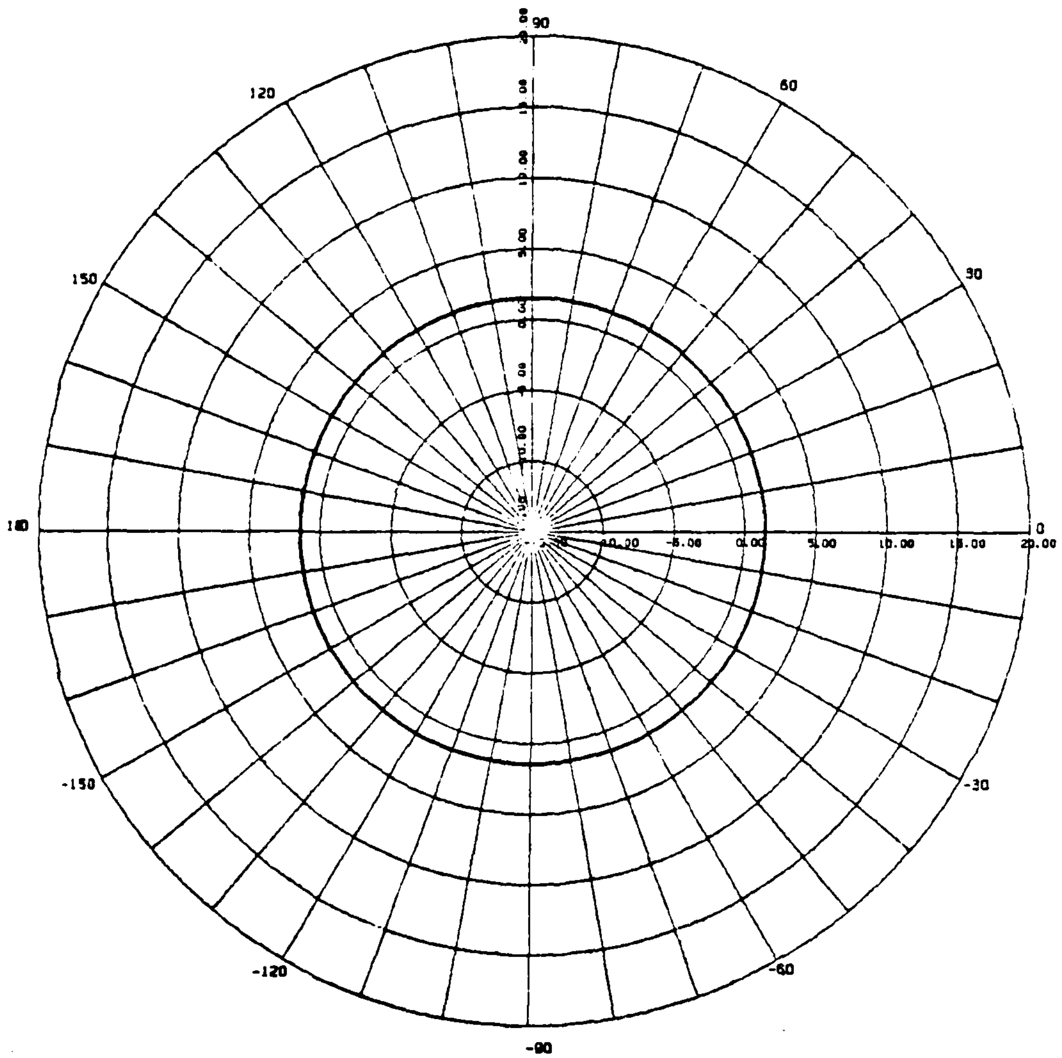
RC-292 / THETA / PHI=90 (LOADED)

SNOW / TROOP CONFIG/75 MHZ



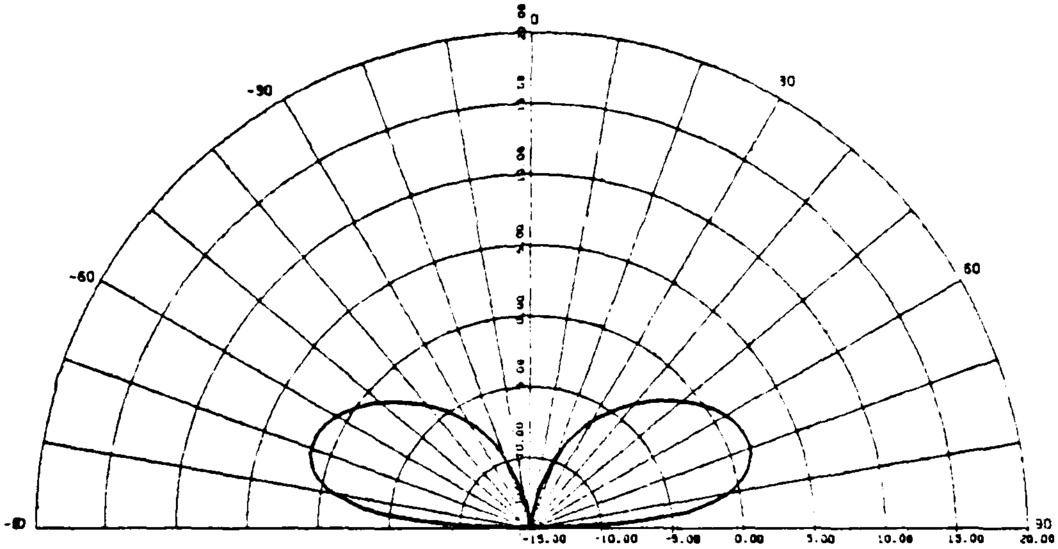
RC-292 / PHI / THETA=70 (LOADED)

SNOW /TM(3MTR MAST) CONFIG/30 MHZ



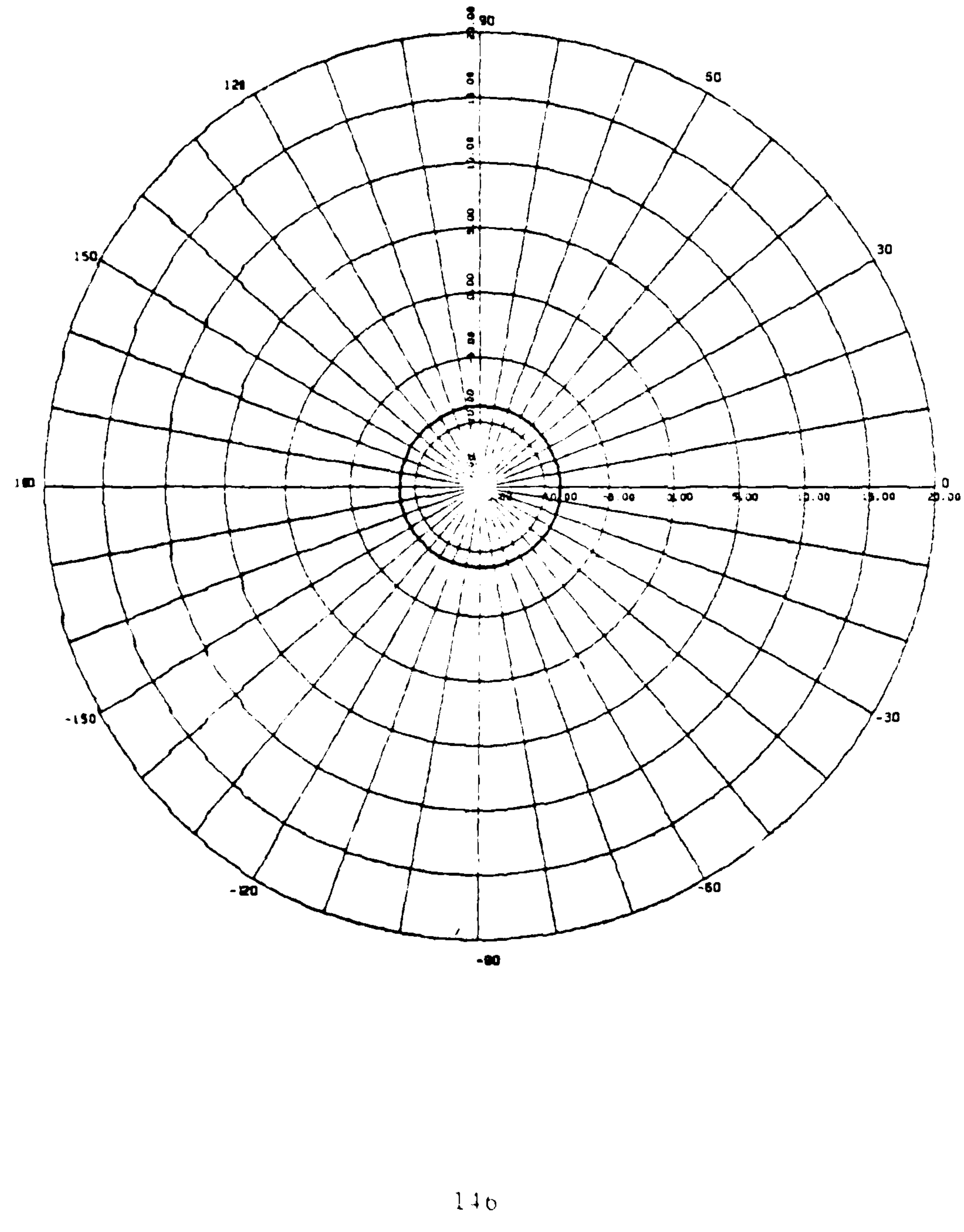
AC-292 / THETA / PHI=90 (LOADED)

SNOW (TM(3MTR MAST) CONFIG/30 MHZ



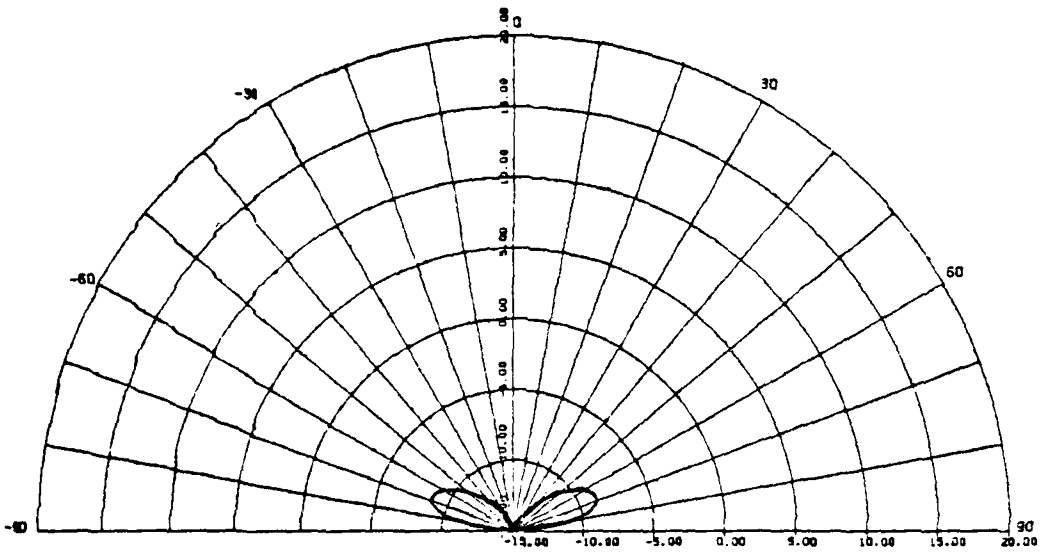
RC-292 / PHI / THETA=70 (LOADED)

SNOW /(C(13MTR MAST) CONFIG/30 MHZ



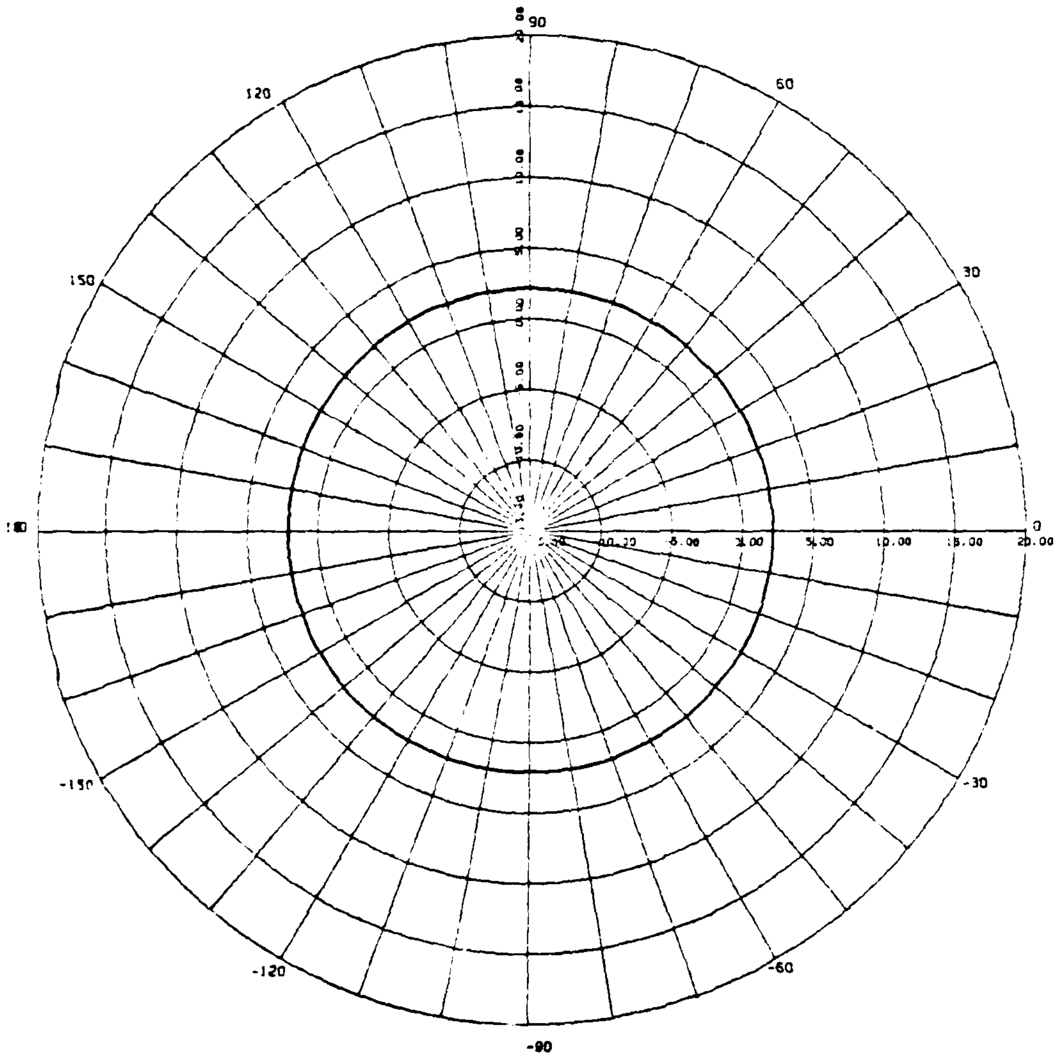
AC-292 / THETA / PHI=90 (LOADED)

SNOW /TC(3MTR MAST) CONFIG/30 MHZ



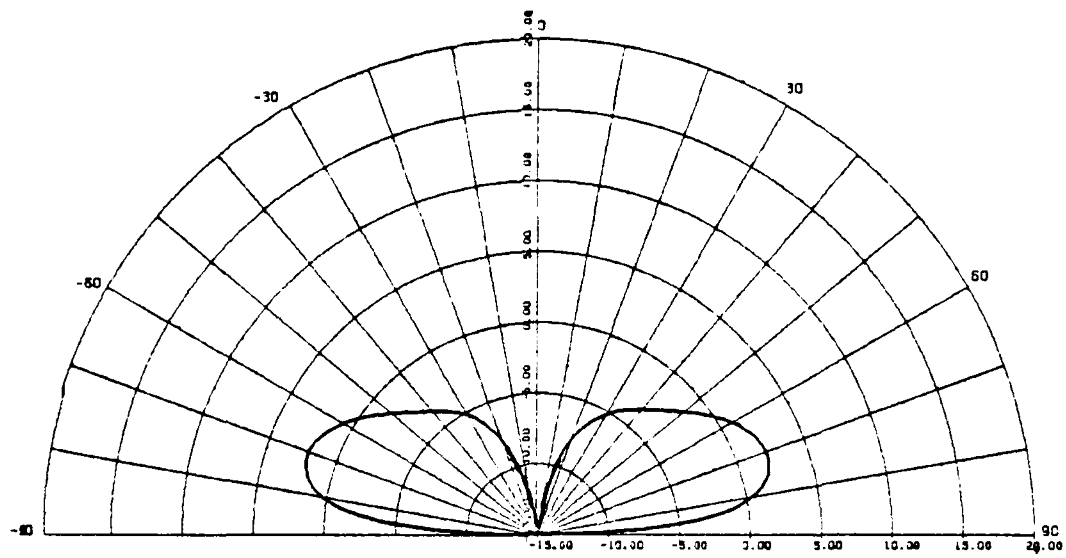
RC-292 / PHI / THETA=70 (LOADED)

SNOW /TM(3MTR MAST) CONFIG/41 MHZ



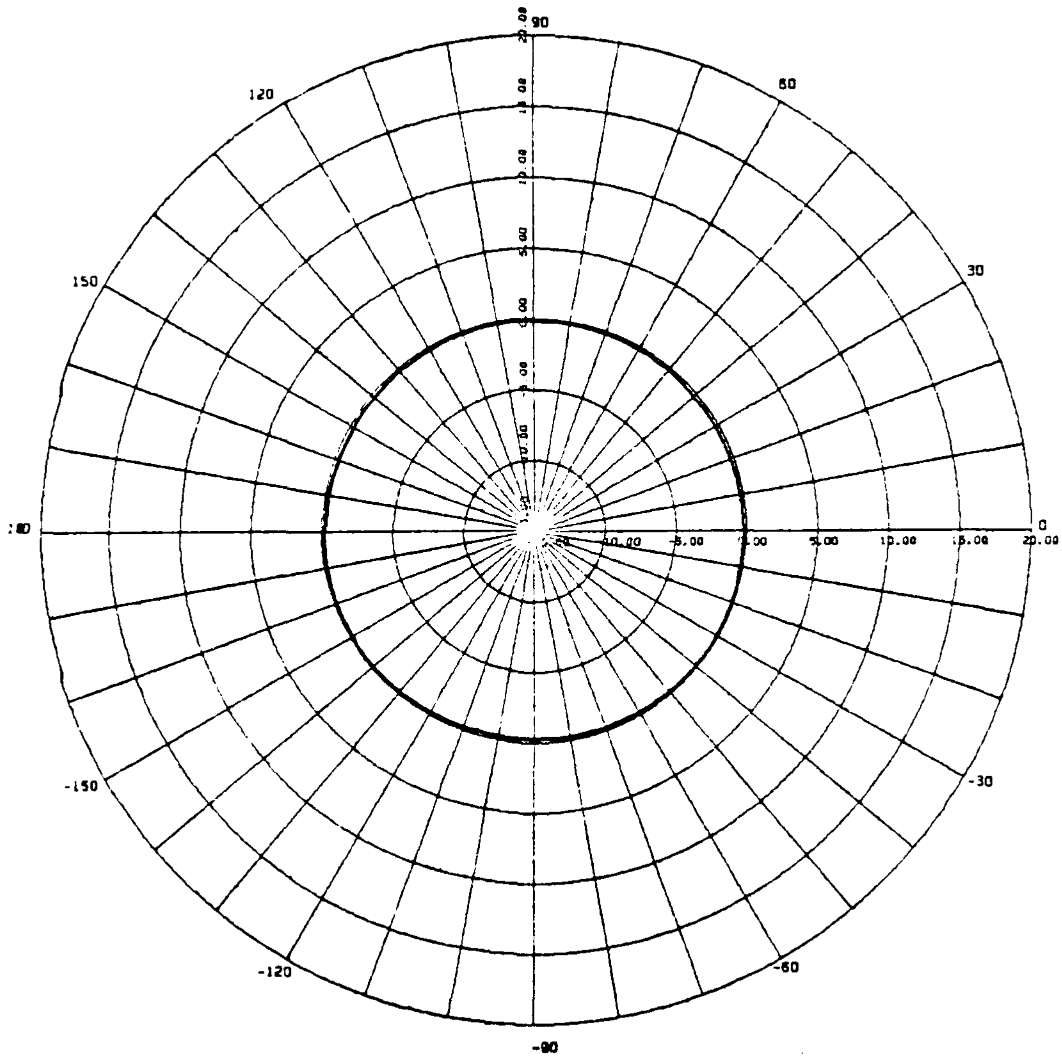
AC-292 / THETA / PHI=90 (LOADED)

SNOW /TM(3MTR MAST) CONFIG/41 MHZ



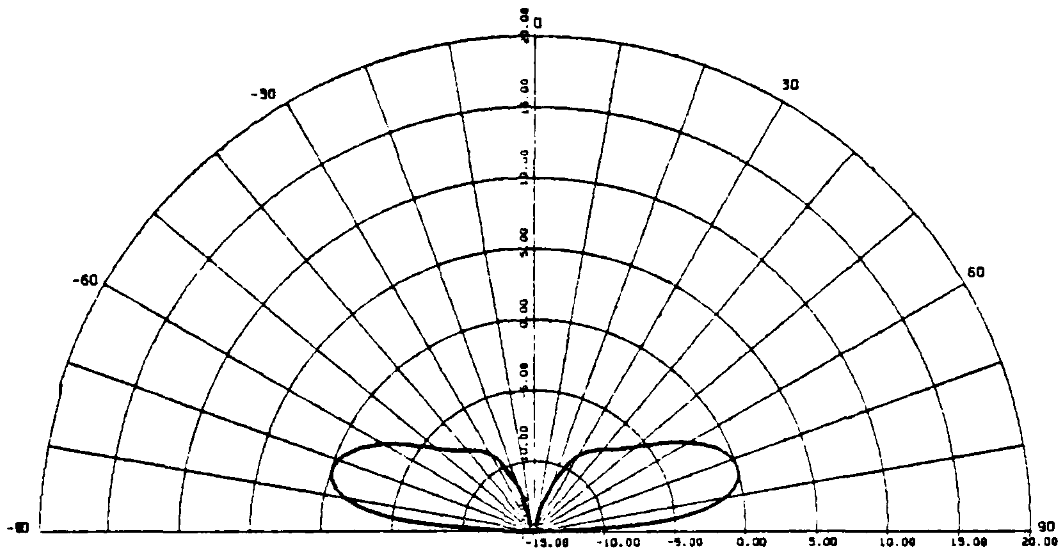
AC-292 / PHI / THETA=70 (LOADED)

SNOW /TM(3MTR MAST) CONFIG/50 MHZ



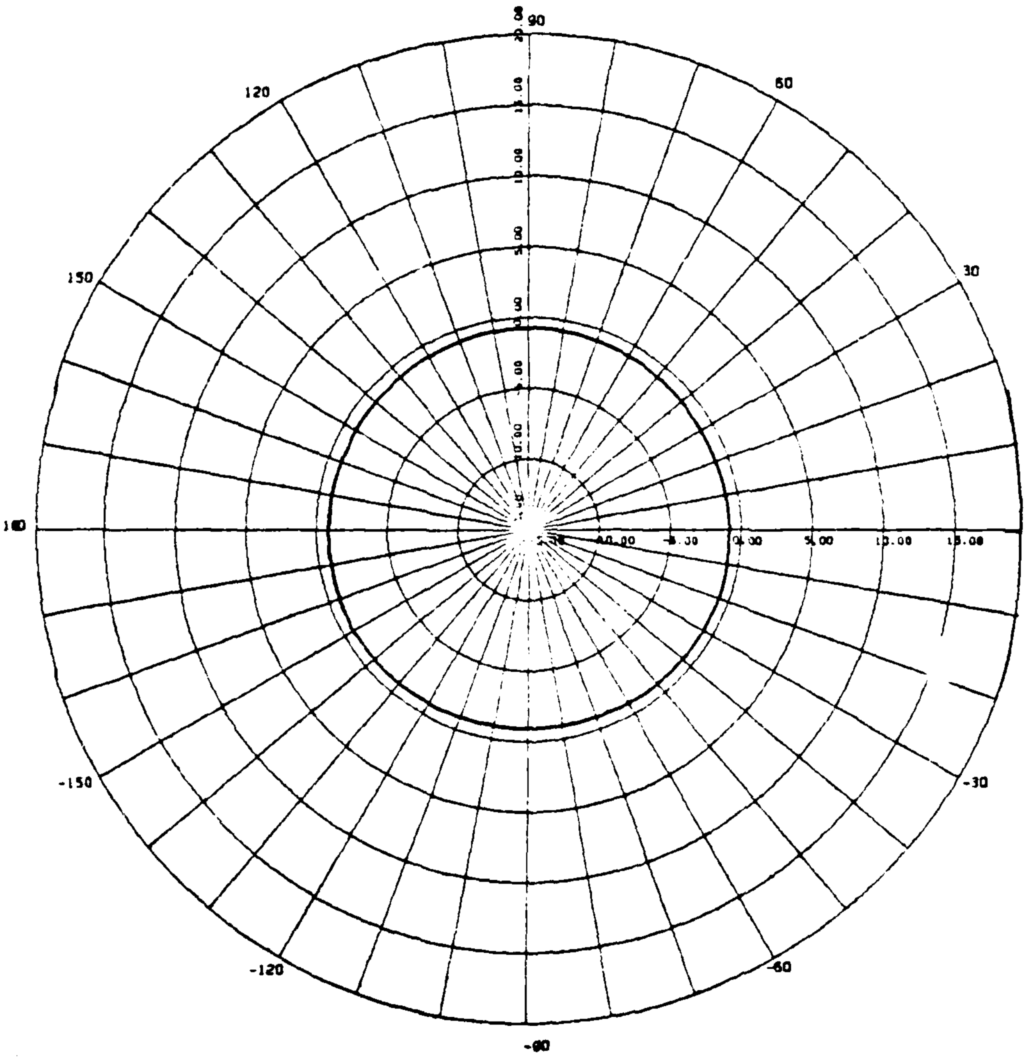
AC-292 / THETA / PHI=90 (LOADED)

SNOW /TM(3MTR MAST) CONFIG/50 MHZ



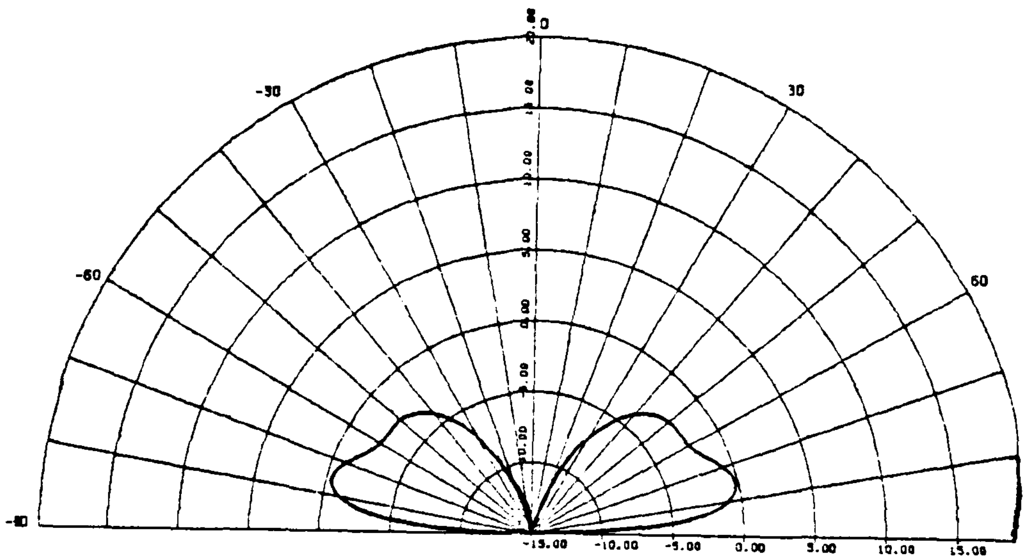
RC-292 / PHI / THETA=70 (LOADED)

SNOW /TM(3MTR MAST) CONFIG/75 MHZ



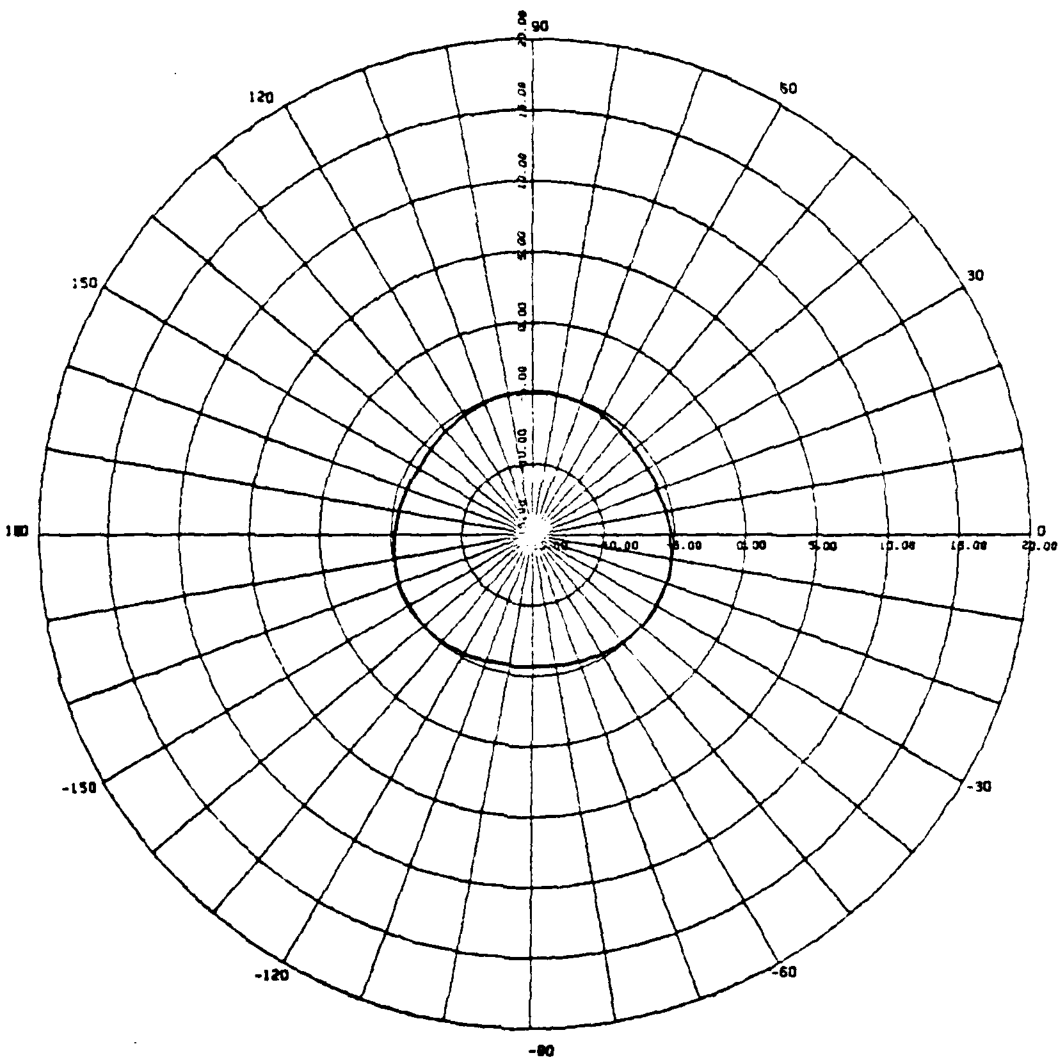
RC-292 / THETA / PHI=90 (LOADED)

SNOW /TM(3MTR MAST) CONFIG/75 MHZ



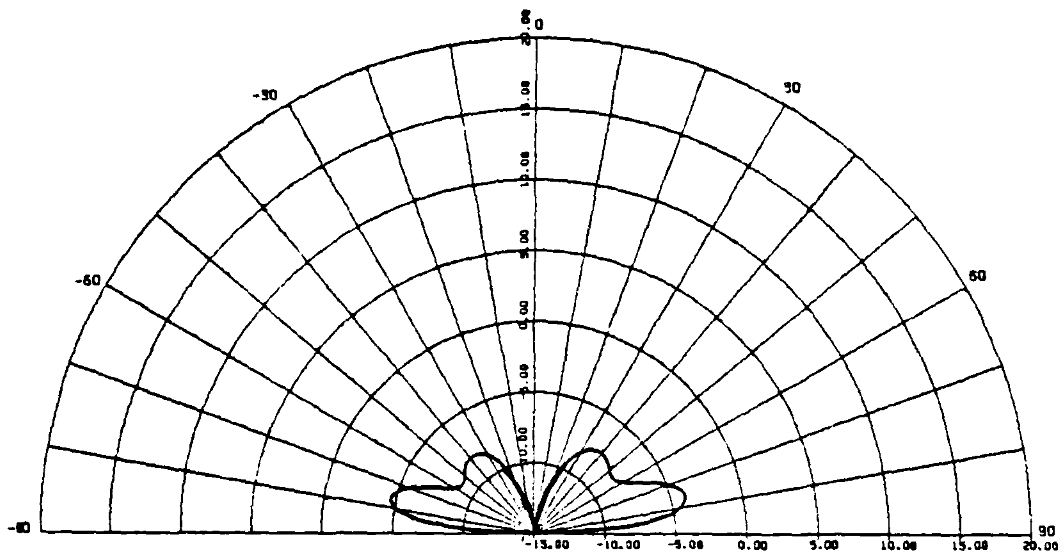
RC-292 / PHI / THETA=70 (LOADED)

SNOW /TC(13MTR MAST) CONFIG/75 MHZ



AC-292 / THETA / PHI=90 (LOADED)

SNOW /TC(3MTR MAST) CONFIG/75 MHZ



APPENDIX B

Contained in this appendix is a listing of the radiation patterns generated by the NEC computer analysis of the MRC-109 VHF vehicular antenna. The heading for each radiation pattern contains the necessary information to analysis the pattern. The first line shows the following:

type antenna / type pattern (phi: horizontal;
theta: vertical) / plane of pattern

The second line shows the following:

ground condition / configuration / frequency

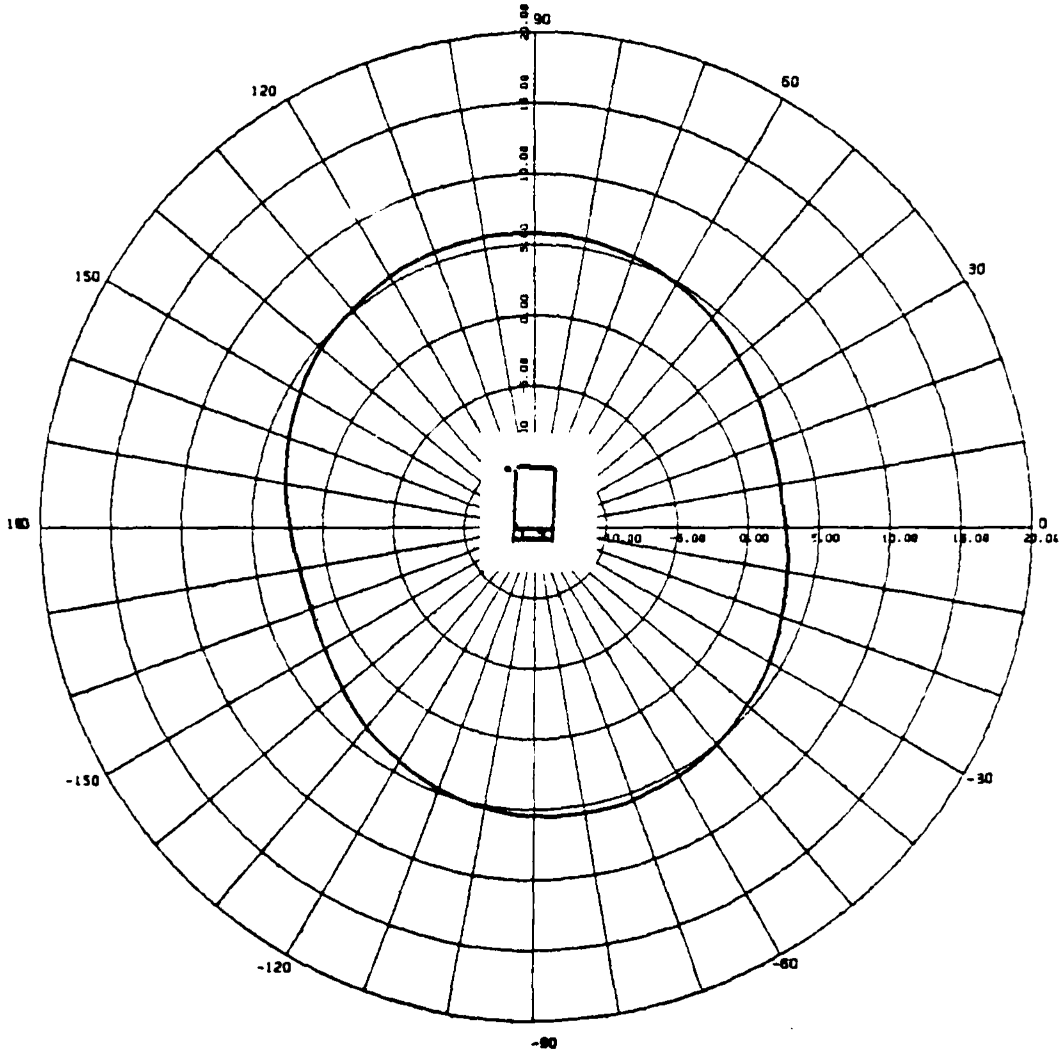
The first sets of patterns include the orientation of the vehicle when the patterns were generated. For the vertical patterns, the arrows on the vehicle orientation indicate the "look" position of the observer to the vehicle

The sets of patterns are arranged for each ground condition analyzed. Each ground condition sub-set contains the three vehicle configurations in packets of twenty-four patterns per configuration. Within each packet there are six patterns, three horizontal (phi) and three vertical (theta), for each of the four frequencies that were examined.

The scale of each polar plot is referenced to isotropic and the scale used must be noted when interpretation of plots is done. Note that for the horizontal pattern for lossy earth and theta equal to 90 degrees, the reference center point begins at -120 dBi.

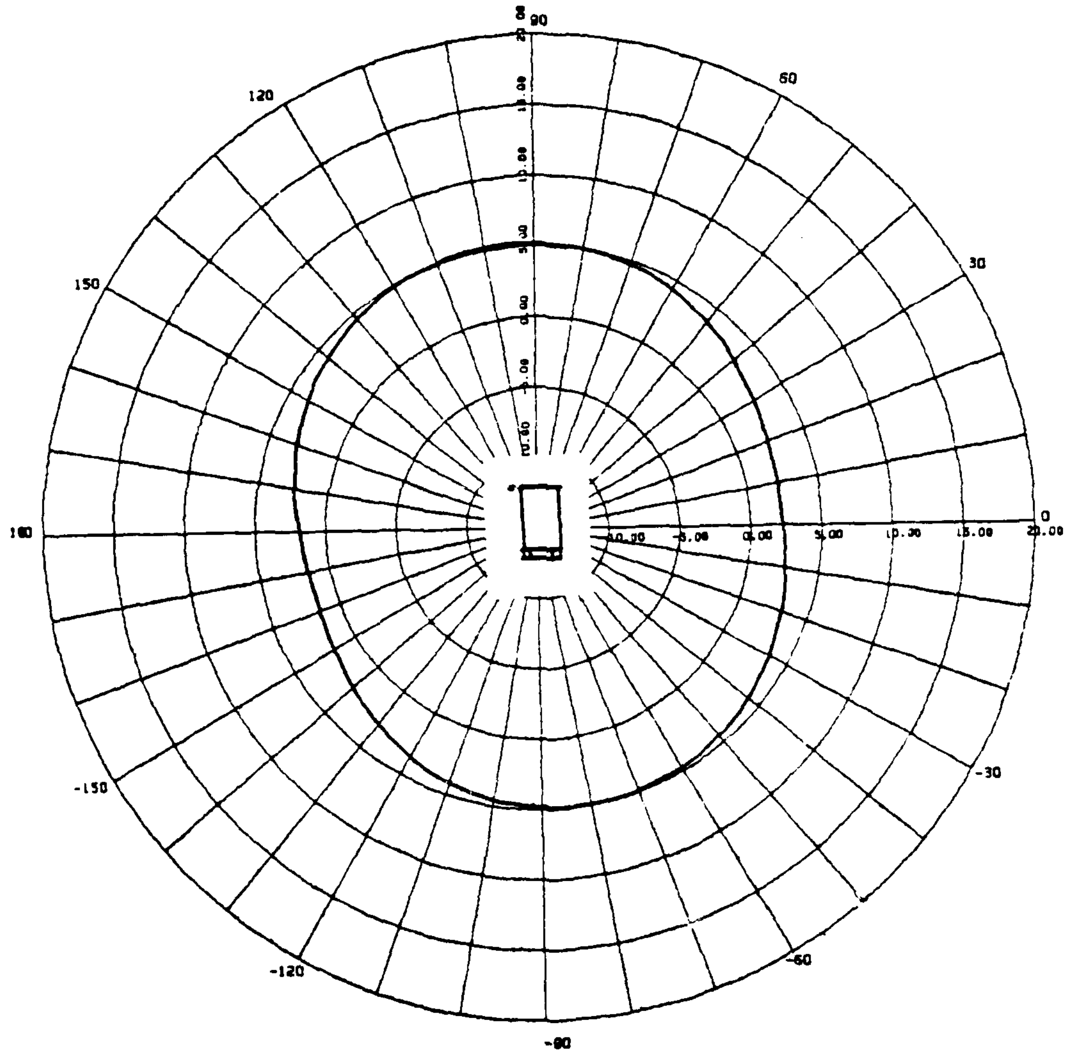
MRC-109 / PHI / THETA=90

PERFECT GROUND / BASIC / 30 MHZ



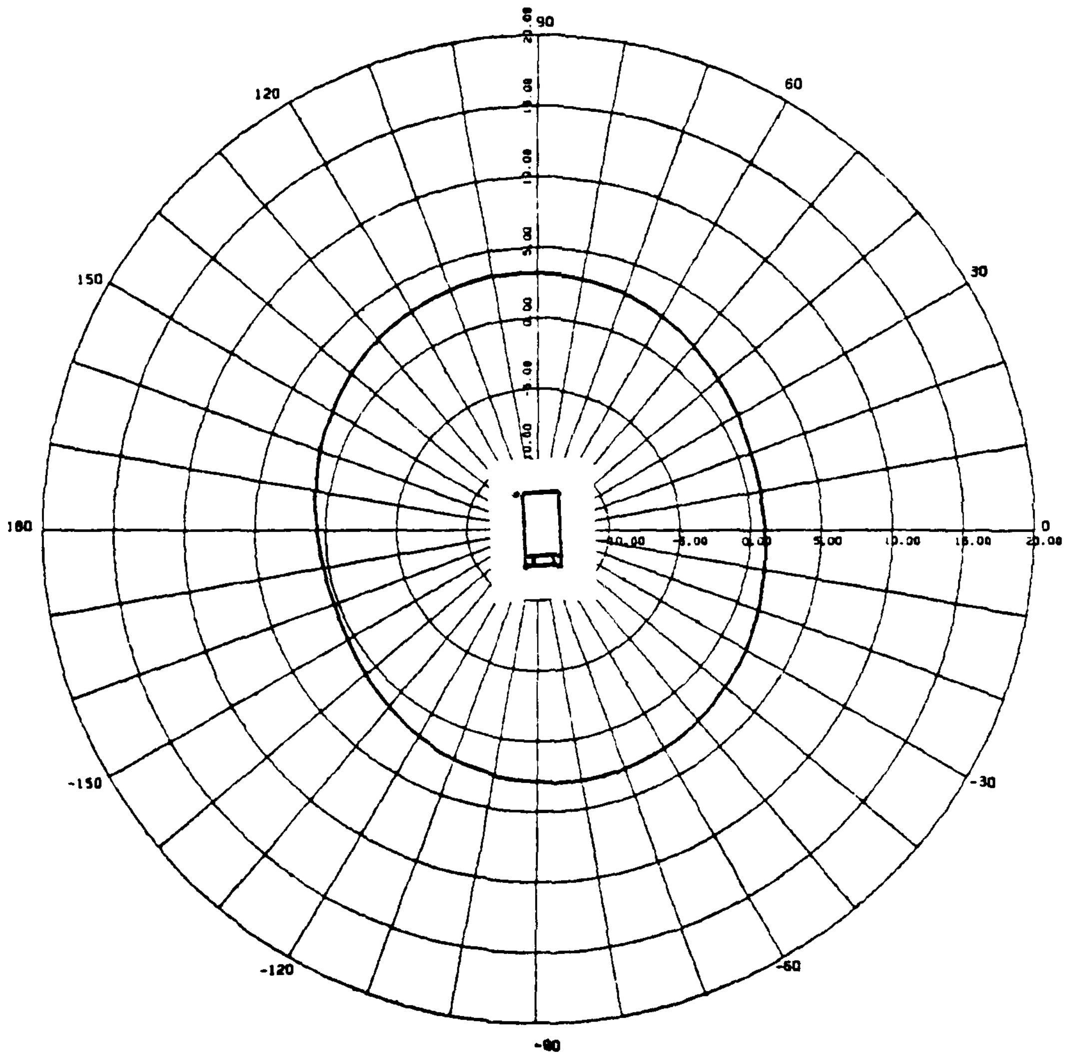
MRC-109 / PHI / THETA= 90

PERFECT GROUND / BASIC / 30 MHZ



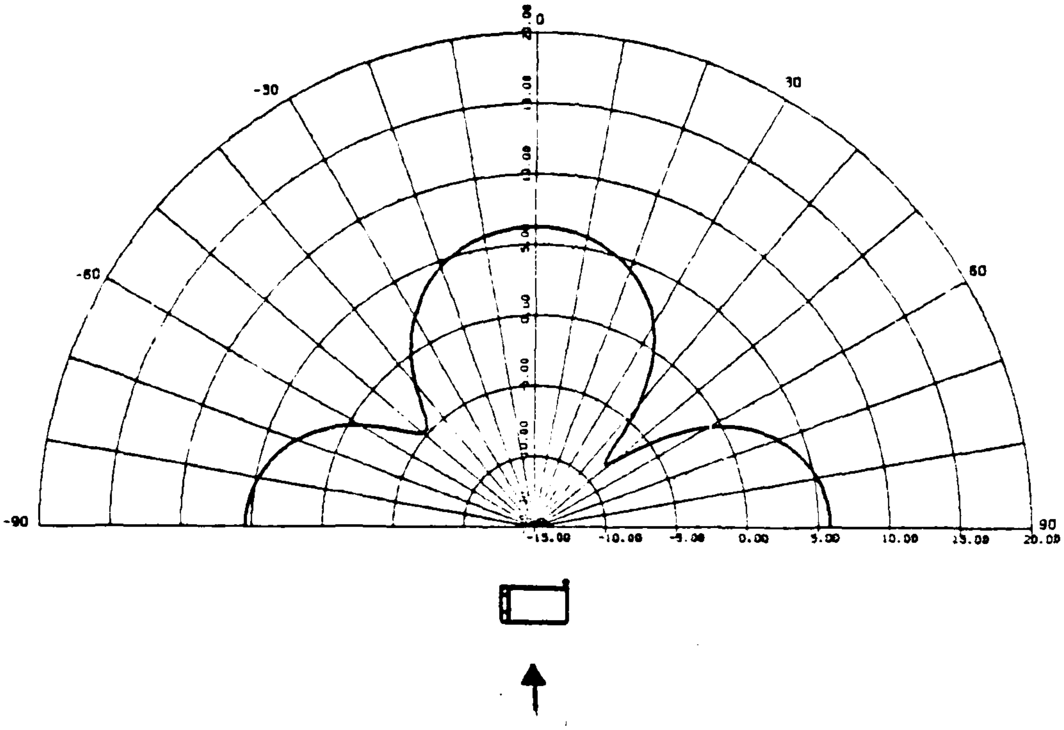
MRC-109 / PHI / THETA= 70

PERFECT GROUND / BASIC / 30 MHZ



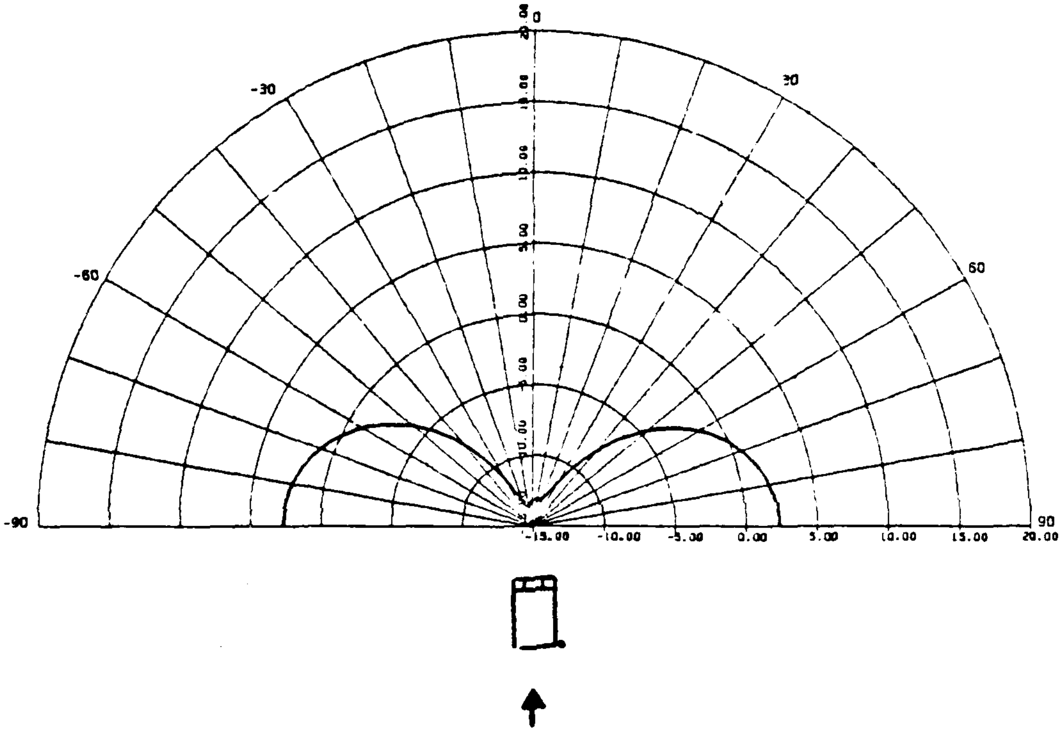
MAC-10S / THETA / PHI = 90

PERFECT GROUND / BASIC / 30 MHZ



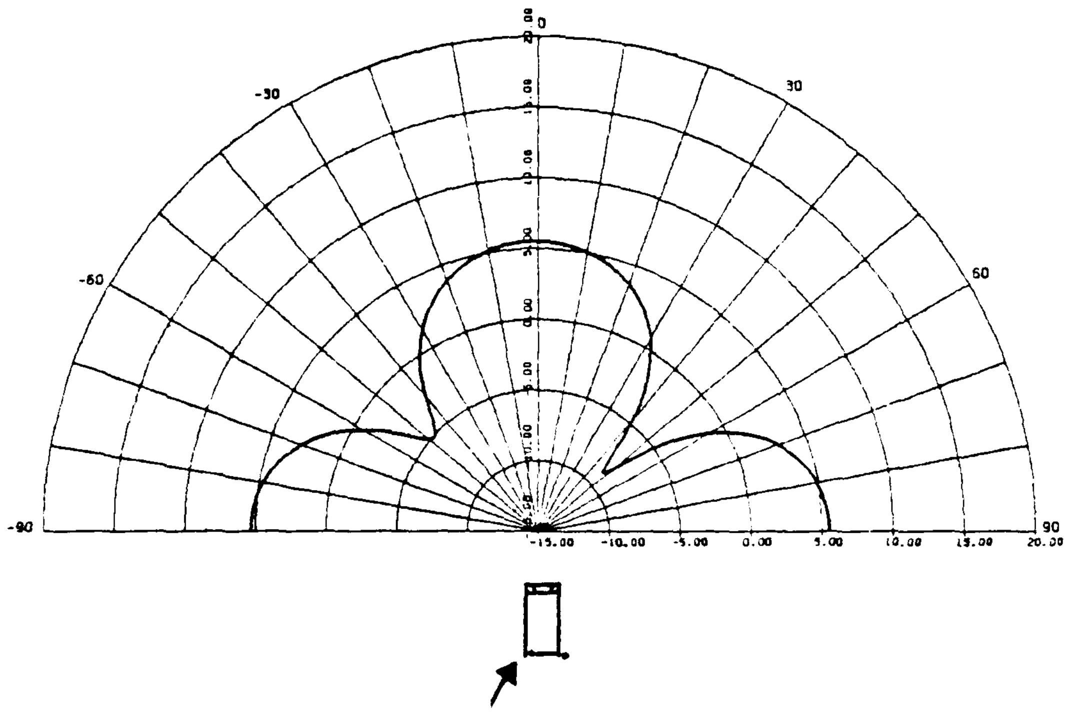
MRC-109 / THETA / PHI = 180

PERFECT GROUND / BASIC / 30 MHZ



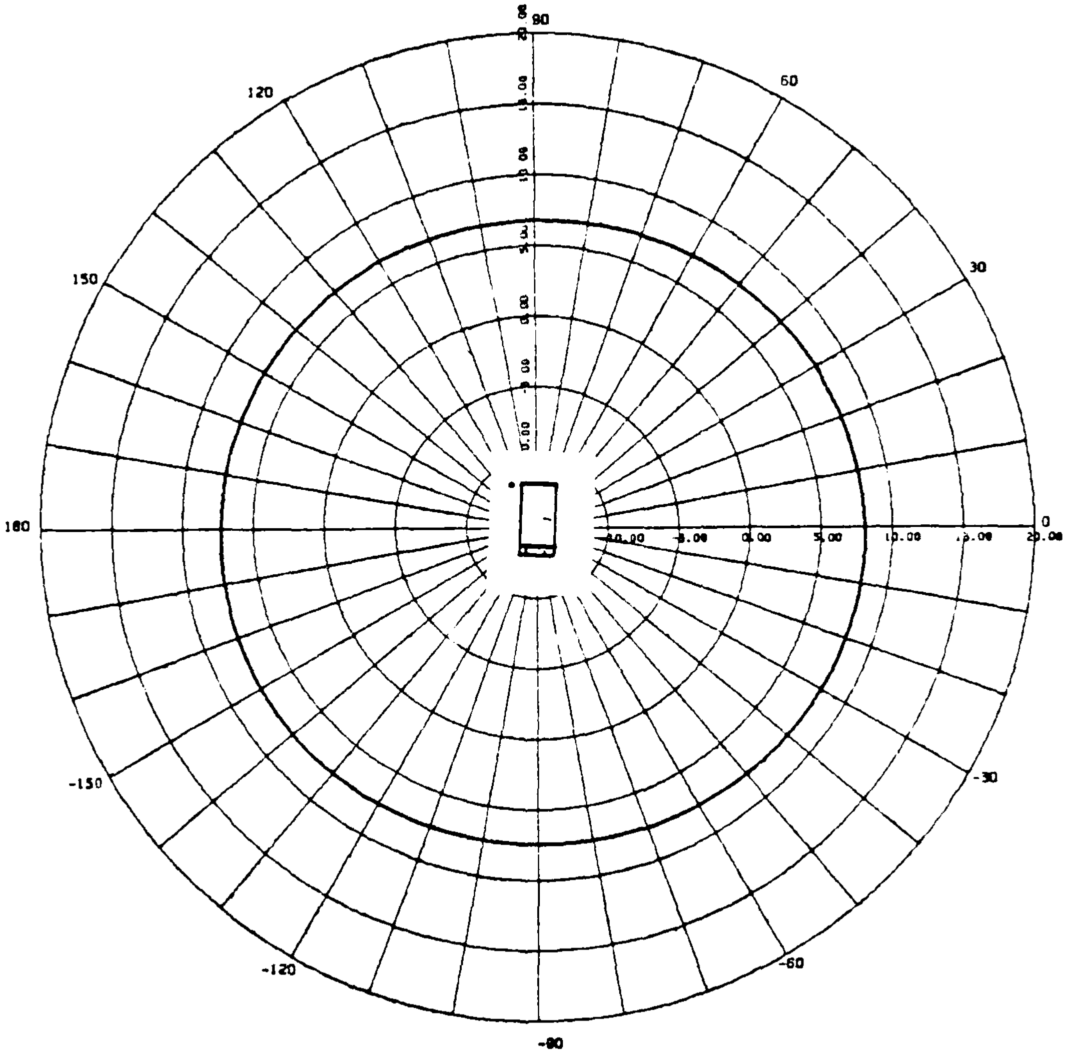
MAC-109 / THETA / PHI = 120

PERFECT GROUND / BASIC / 30 MHZ



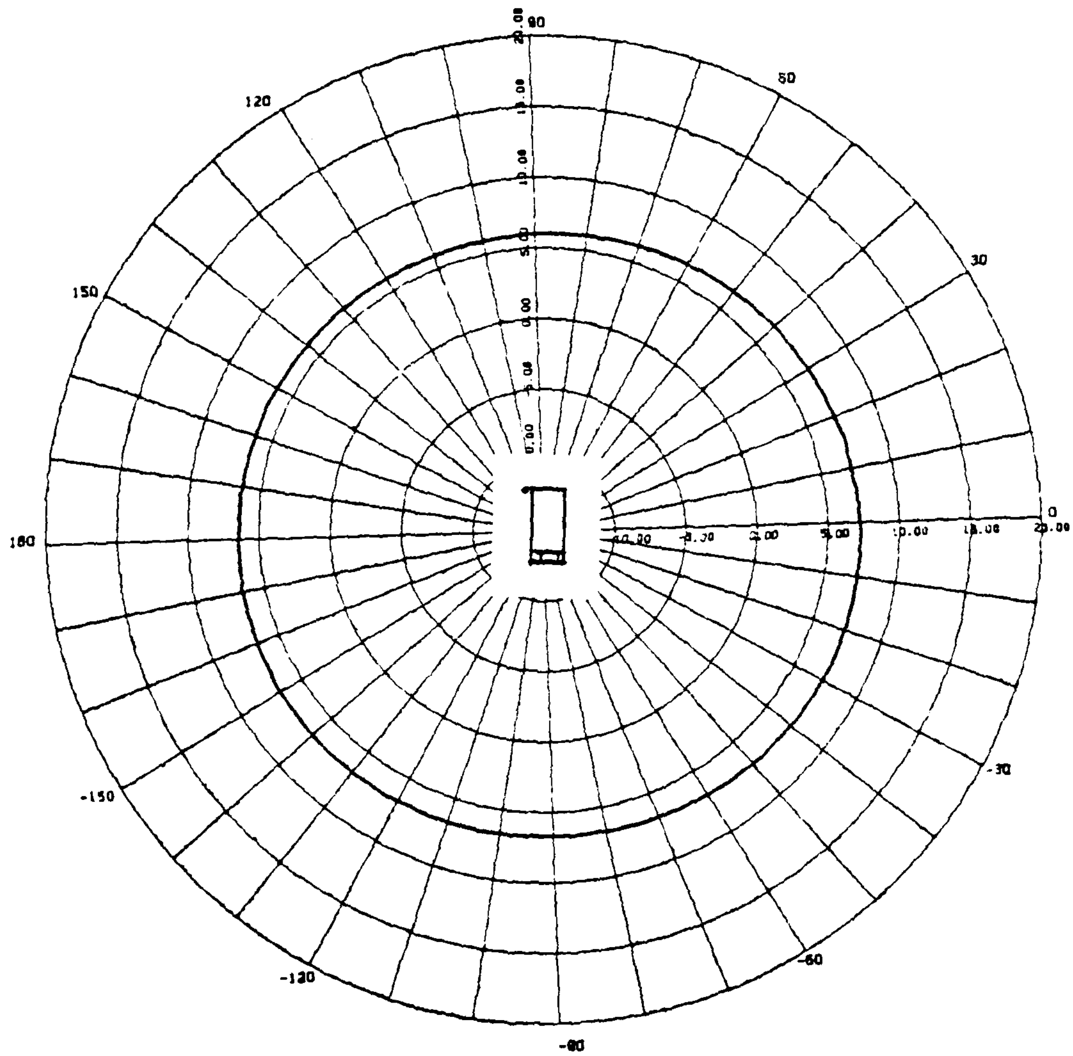
MRC-109 / PHI / THETA=90

PERFECT GROUND / BASIC / 41 MHZ



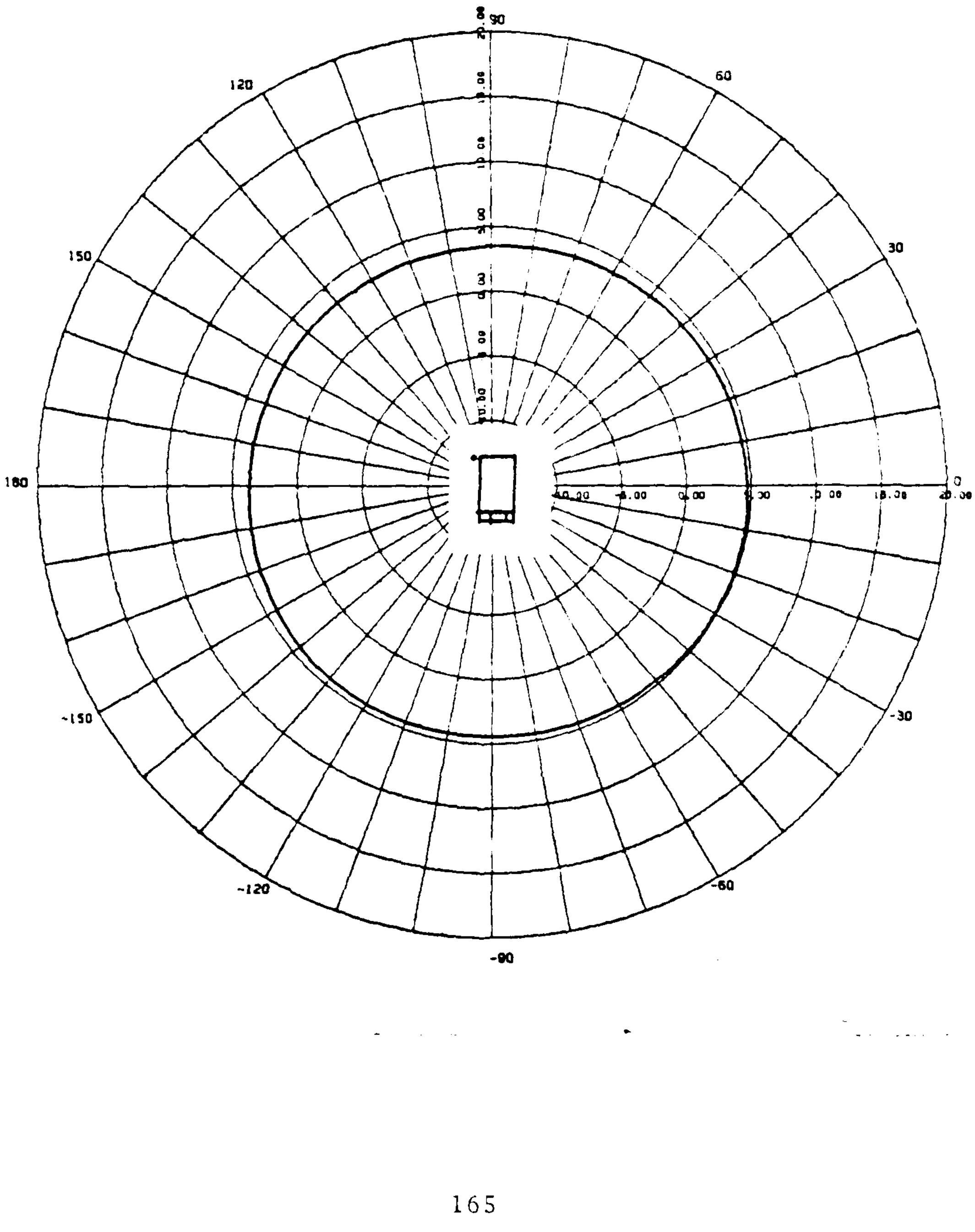
MRC-109 / PHI / THETA= 80

PERFECT GROUND / BASIC / 41 MHZ



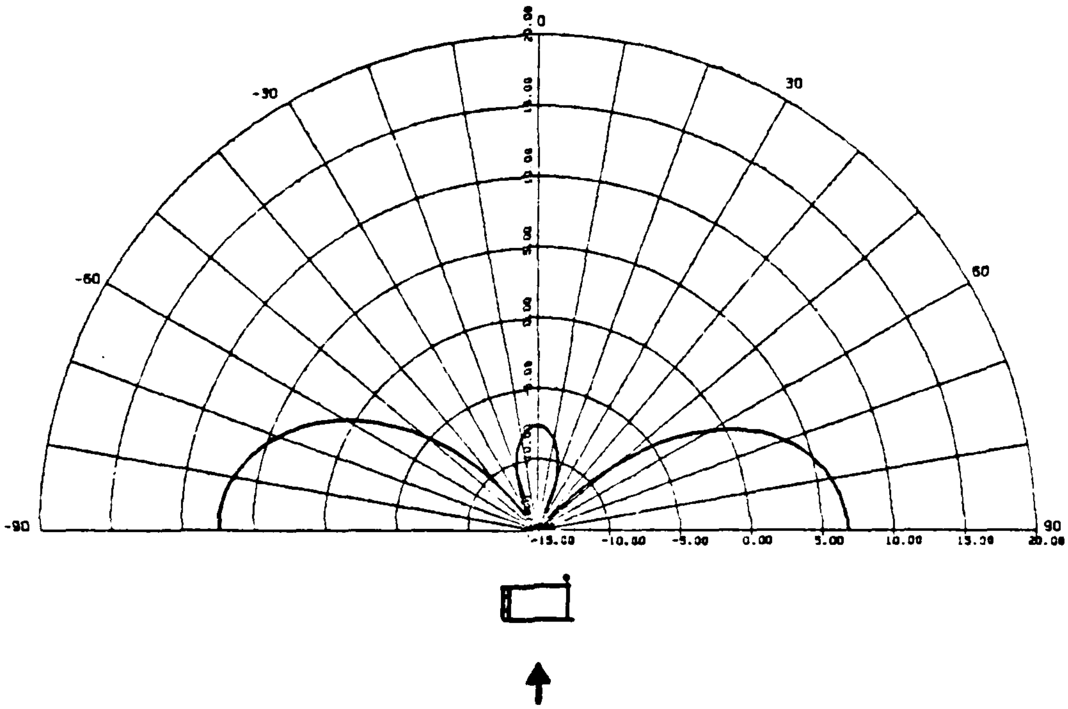
MRC-109 / PHI / THETA= 70

PERFECT GROUND / BASIC / 41 MHZ



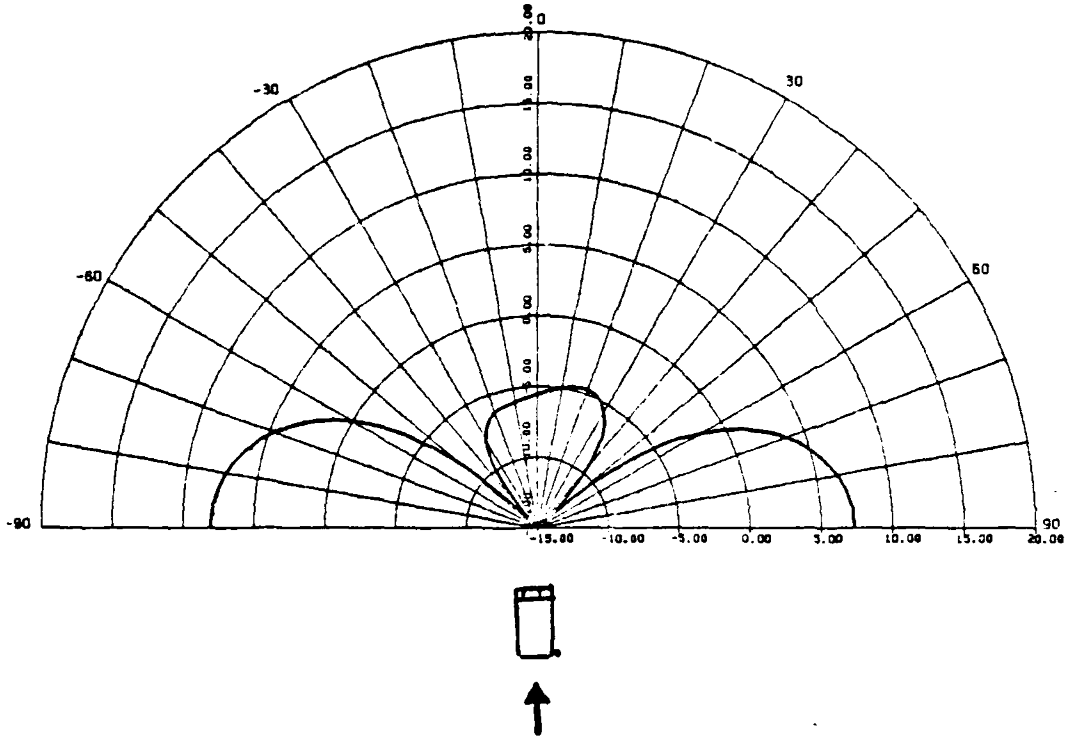
MRC-109 / THETA / PHI = 90

PERFECT GROUND / BASIC / 41 MHZ



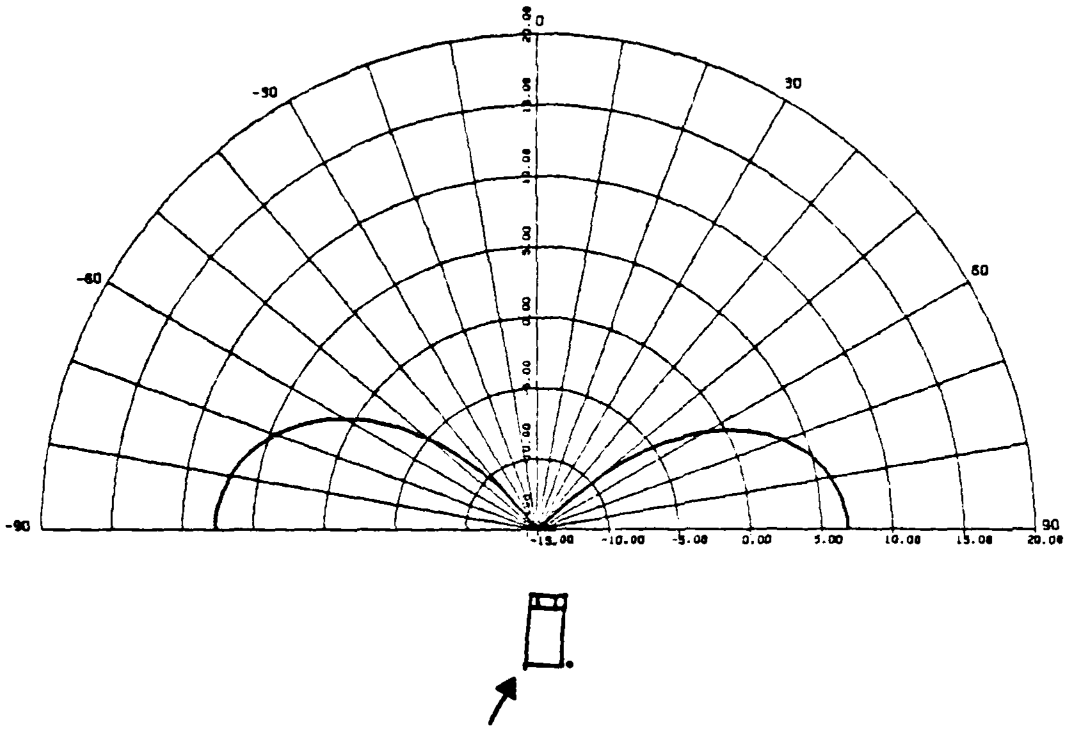
MAC-109 / THETA / PHI = 180

PERFECT GROUND / BASIC / 41 MHZ



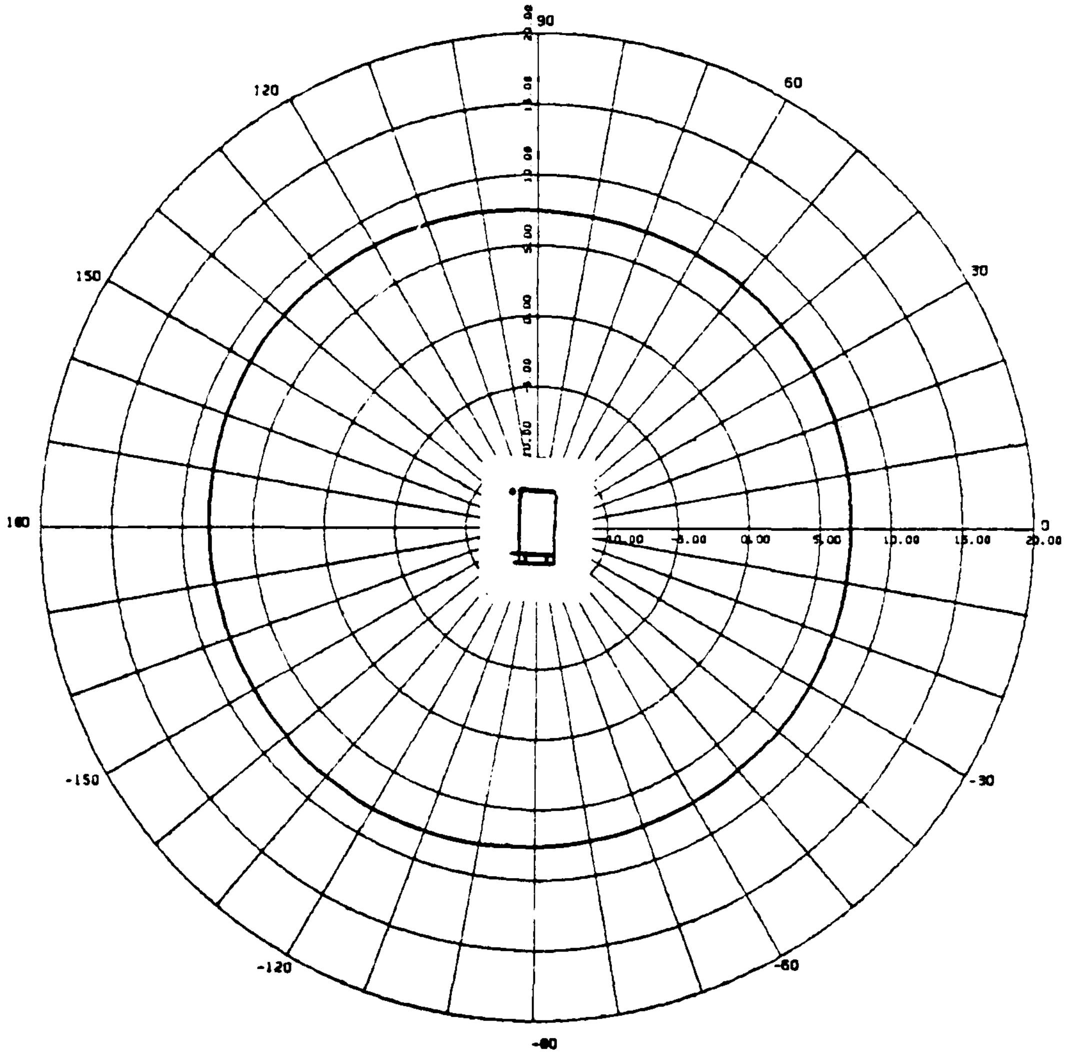
MRC-109 / THETA / PHI = 120

PERFECT GROUND / BASIC / 41 MHZ



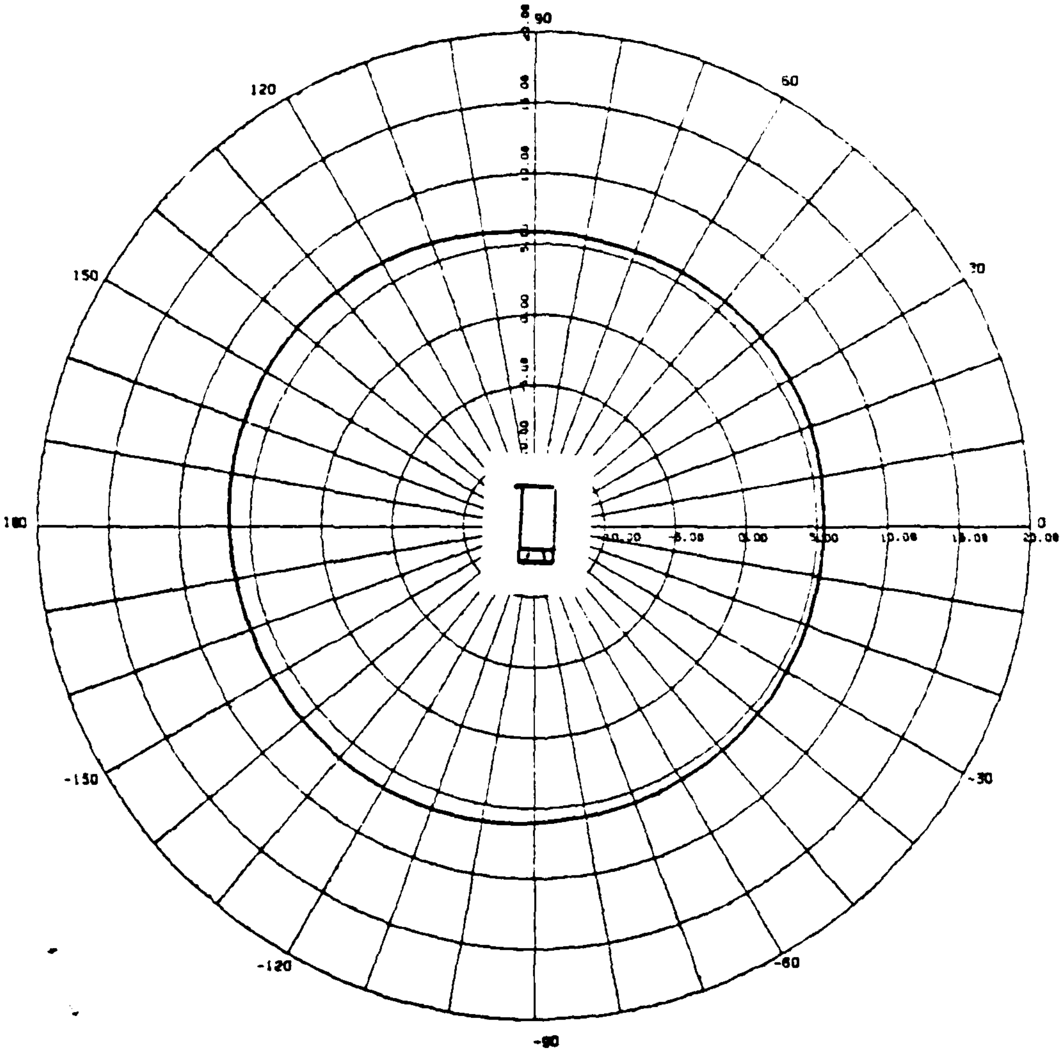
MAC-109 / PHI / THETA=30

PERFECT GROUND / BASIC / 50 MHZ



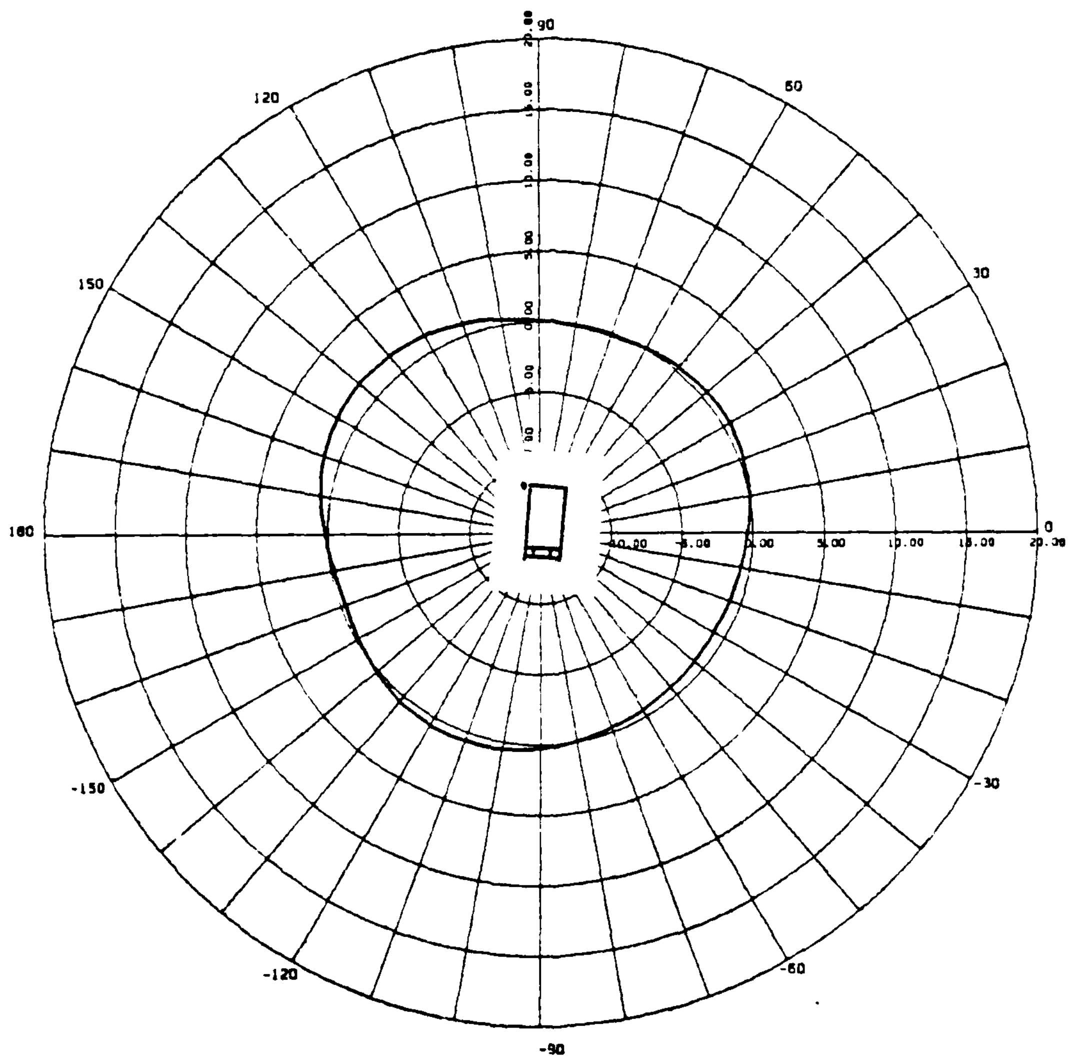
MRC-103 / PHI / THETA= 80

PERFECT GROUND / BASIC / 50 MHZ



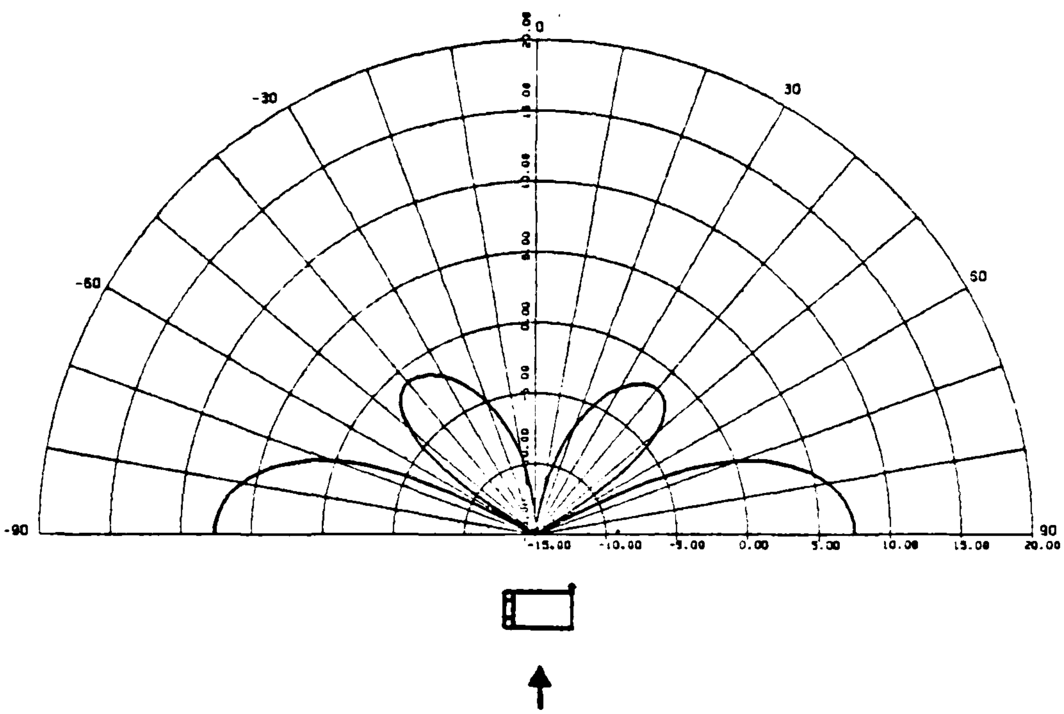
MRC-109 / PHI / THETA= 70

PERFECT GROUND / BASIC / 50 MHZ



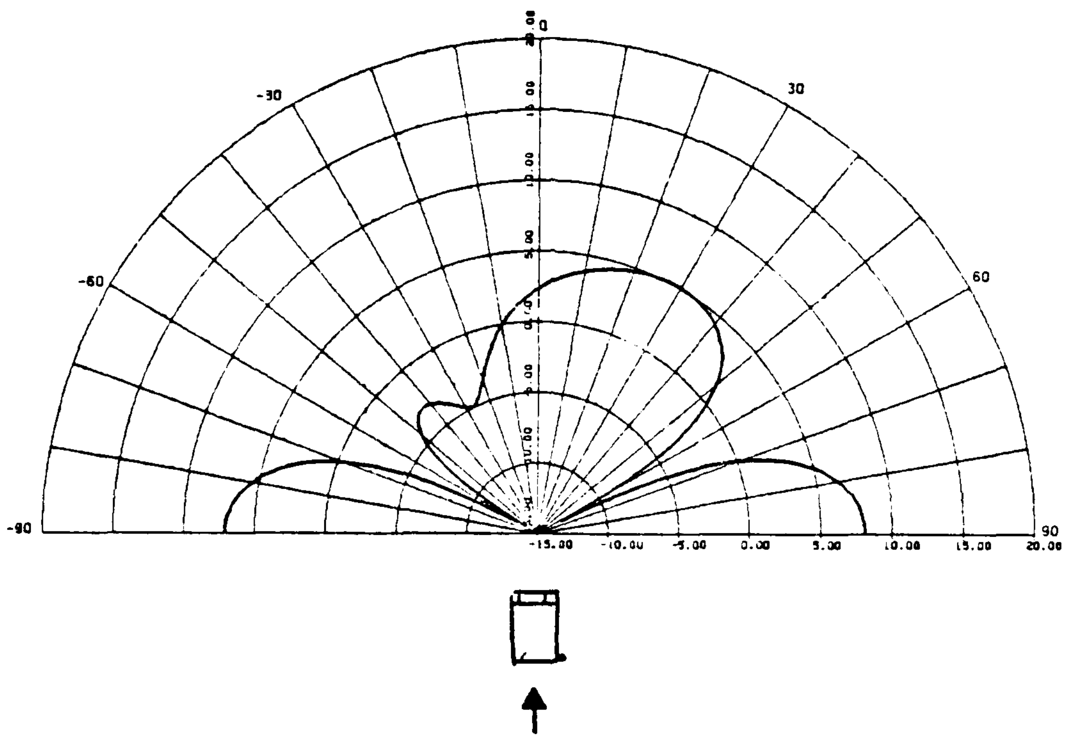
MRC-109 / THETA / PHI = 90

PERFECT GROUND / BASIC / 50 MHZ



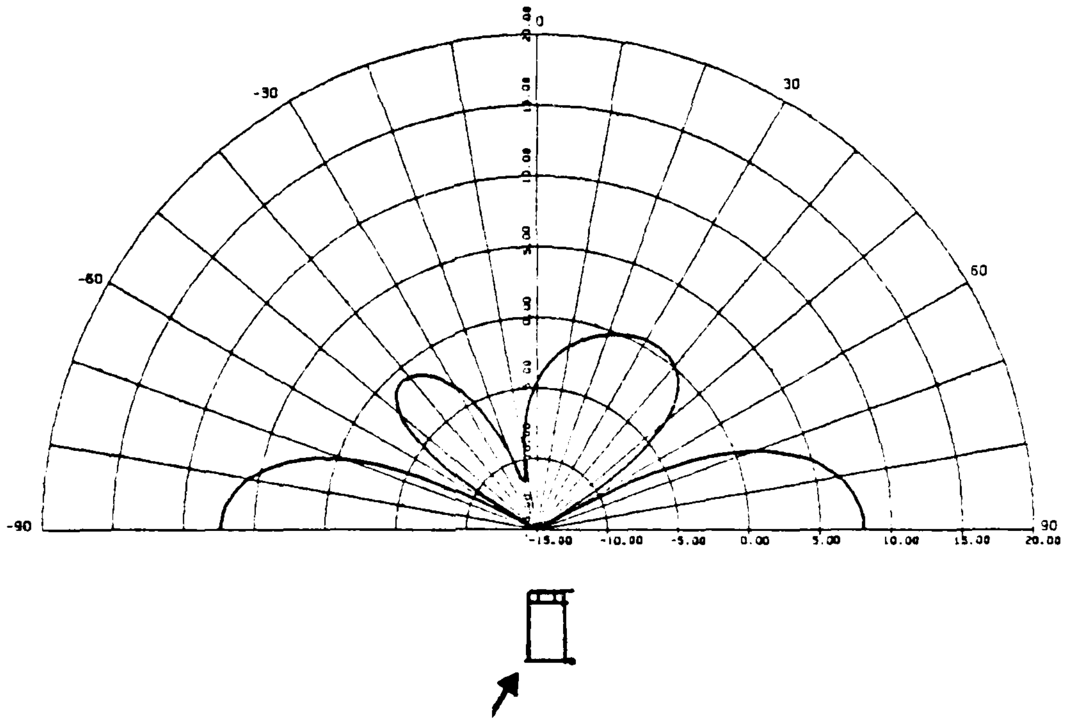
MAC-109 / THETA / PHI = 180

PERFECT GROUND / BASIC / 50 MHZ



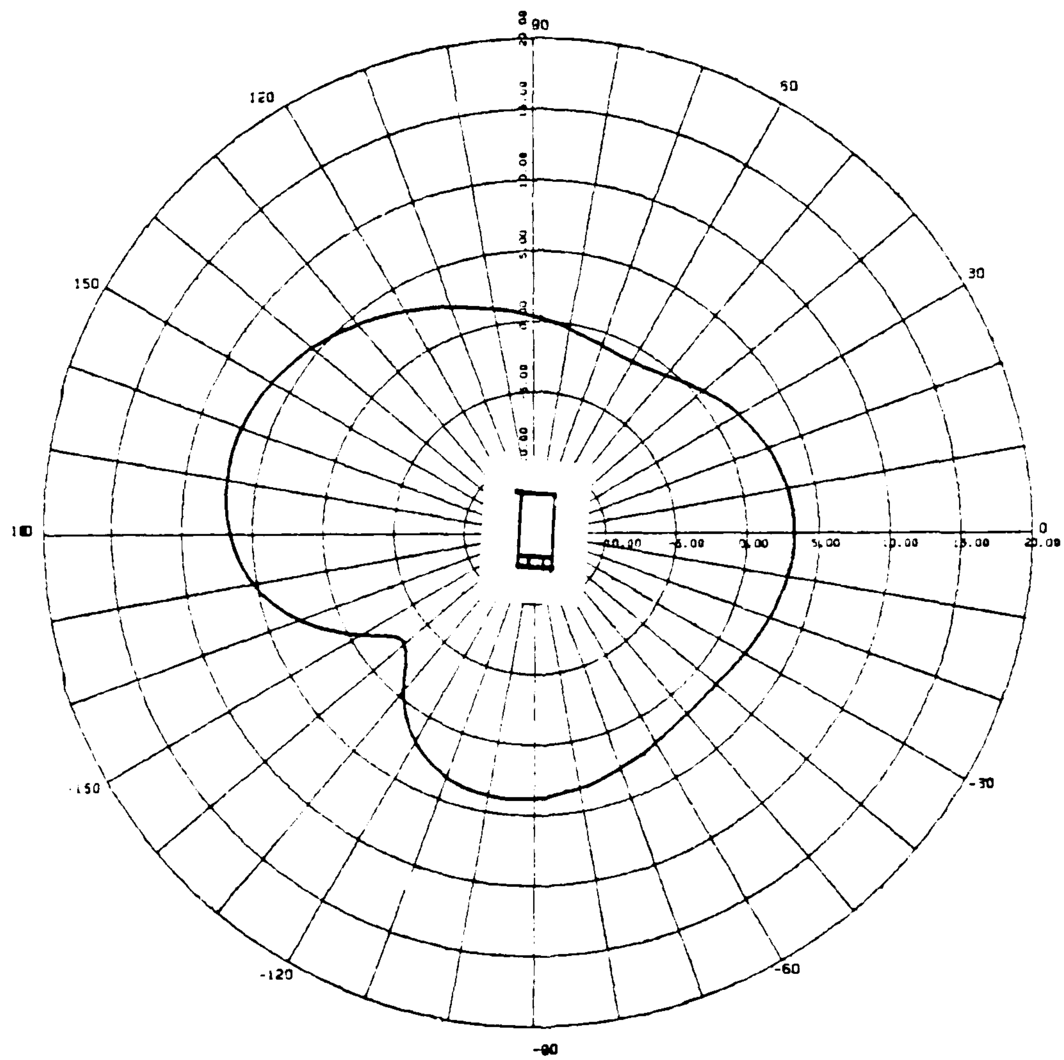
MAC-103 / THETA / PHI = 120

PERFECT GROUND / BASIC / 50 MHZ



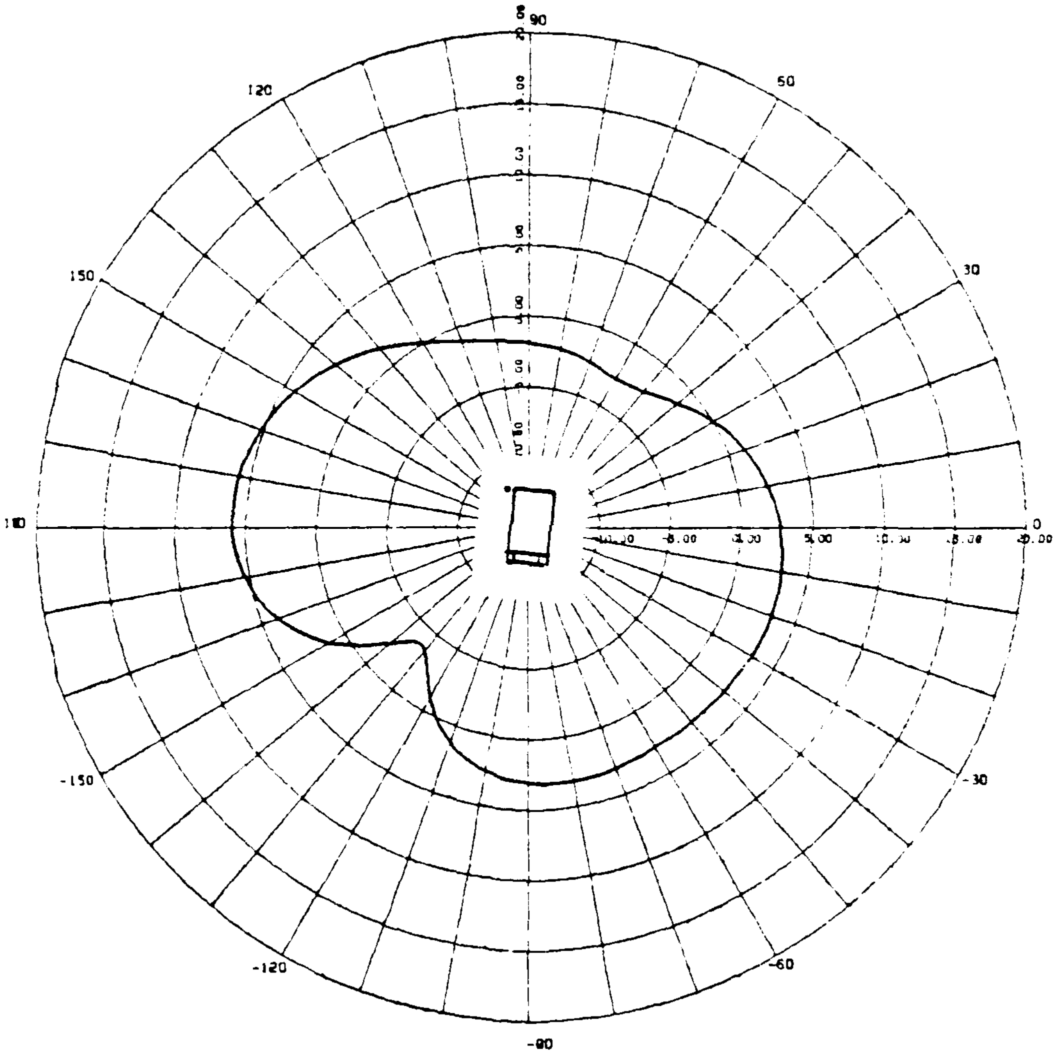
MAC-109 / PHI / THETA=90

PERFECT GROUND / BASIC / 75 MHZ



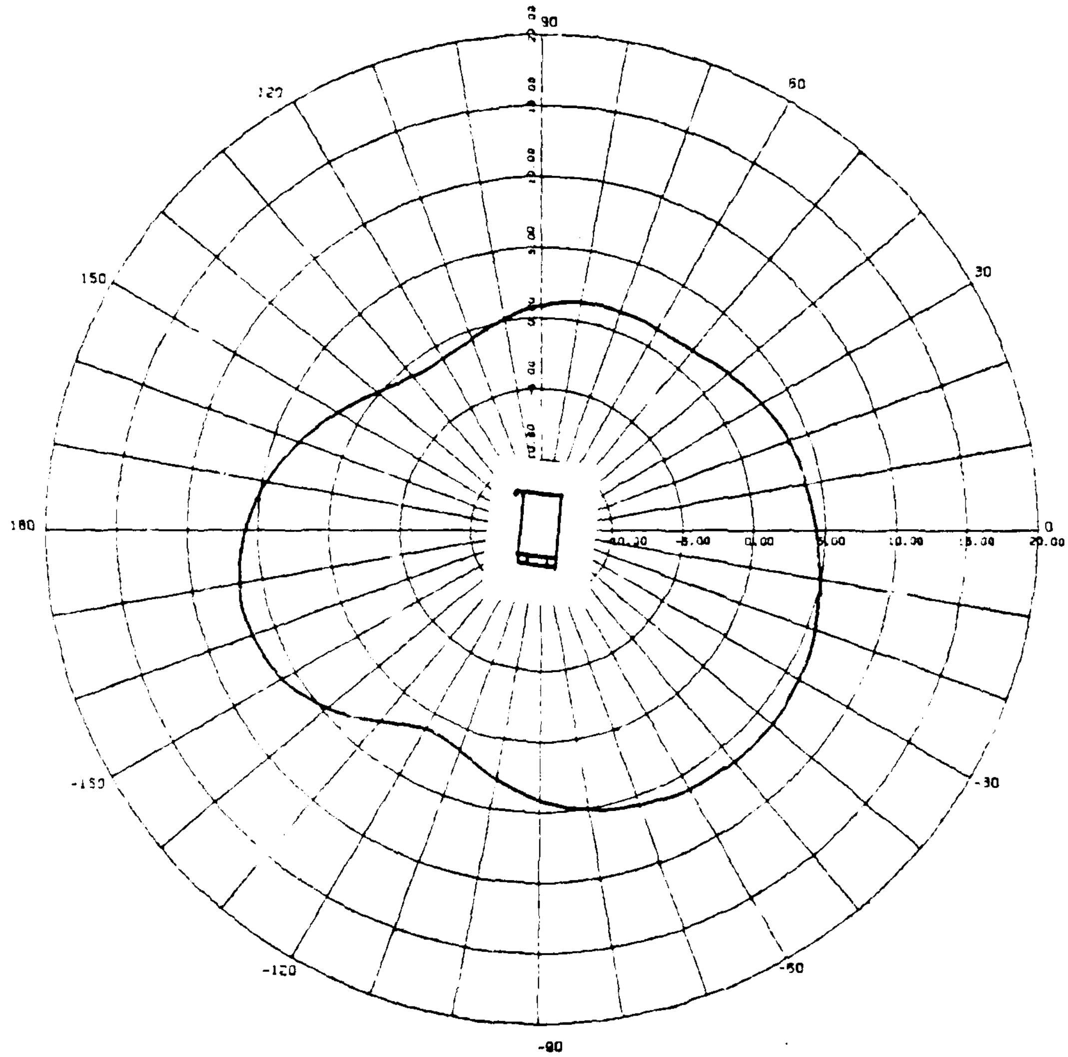
MAC-103 / PHI / THETA= 80

PERFECT GROUND / BASIC / 75 MHZ



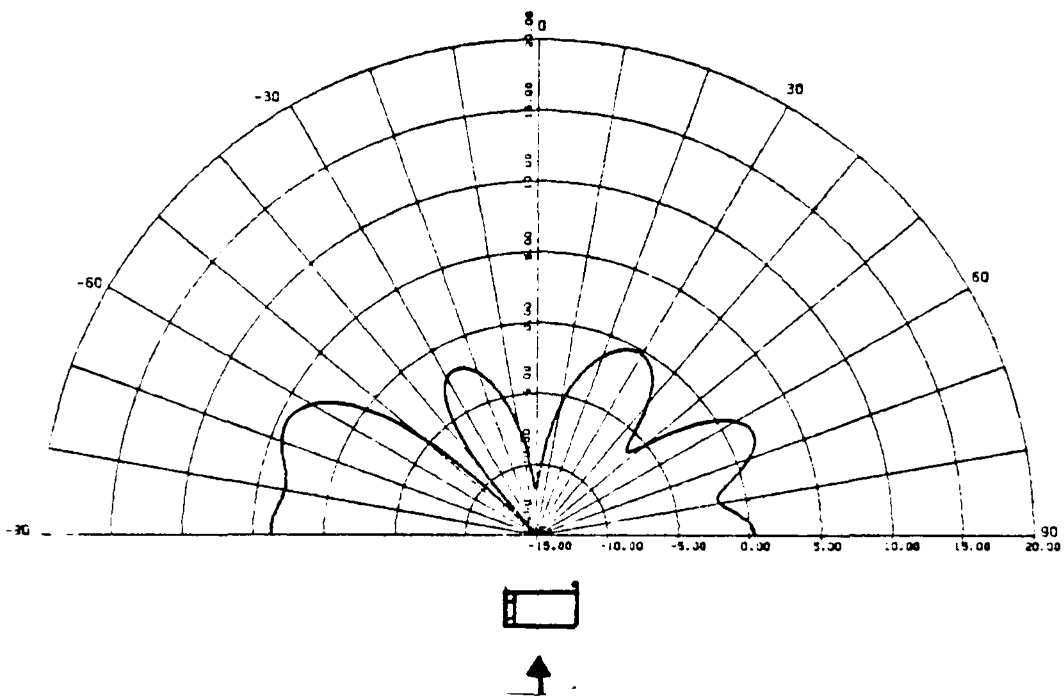
MAG-LOG / PHI / THETA= 70

PERFECT GROUND / BASIC / 75 MHZ



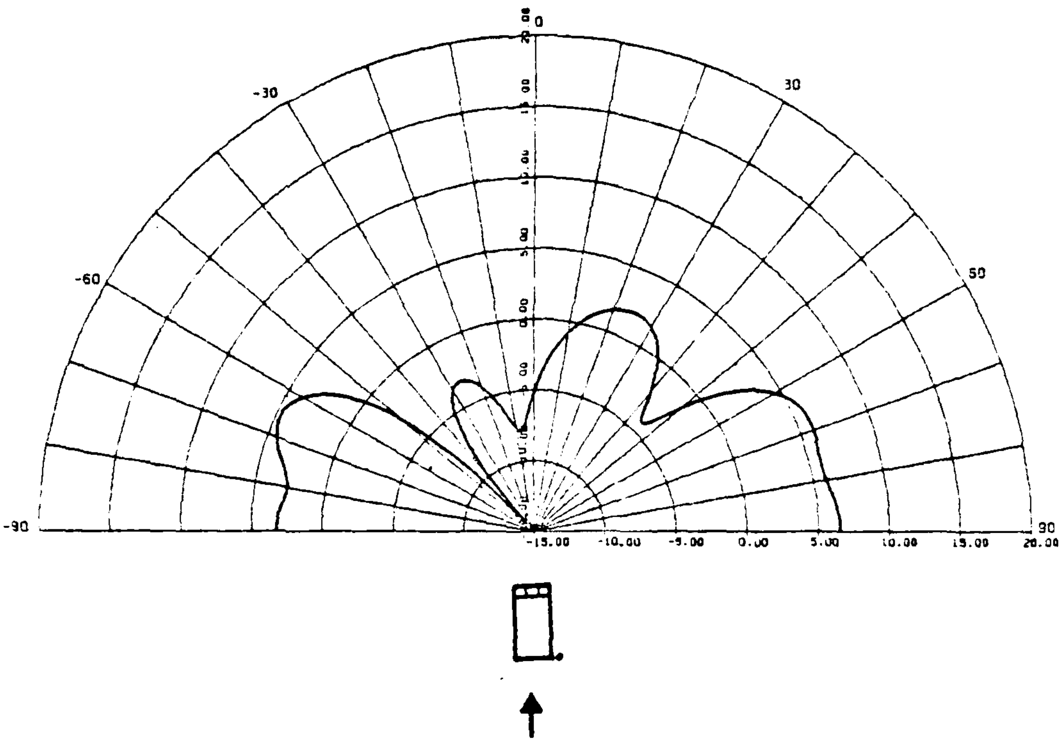
MRC-109 / THETA / PHI = 90

PERFECT GROUND / BASIC / 75 MHZ



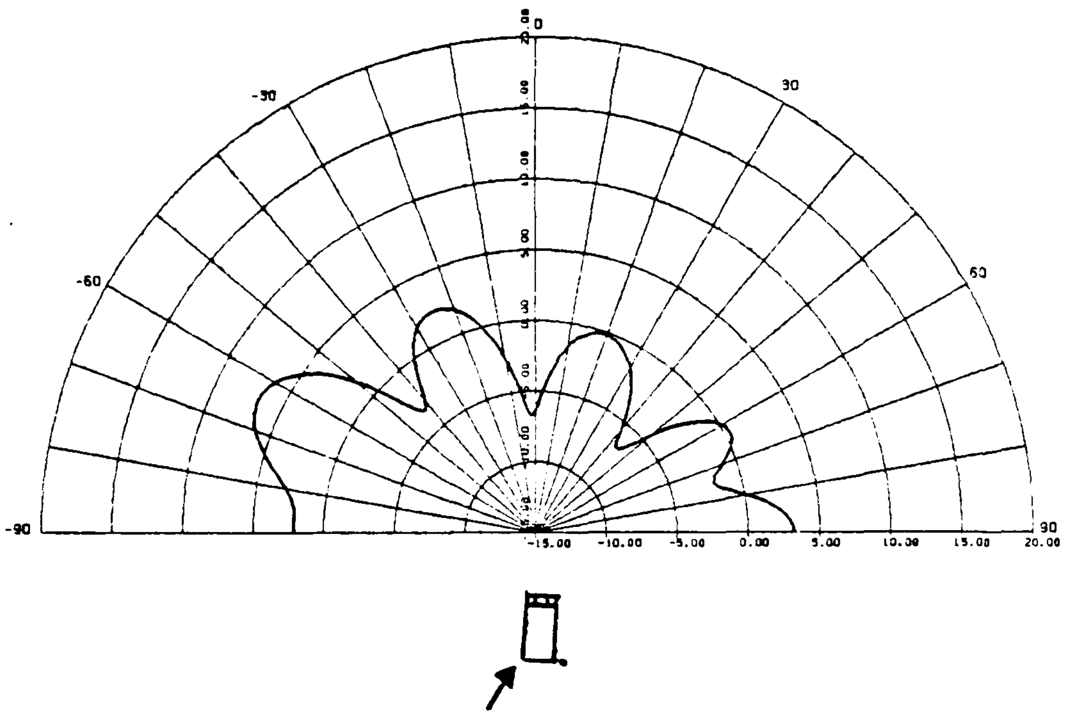
MAC-109 / THETA / PHI = 180

PERFECT GROUND / BASIC / 75 MHZ



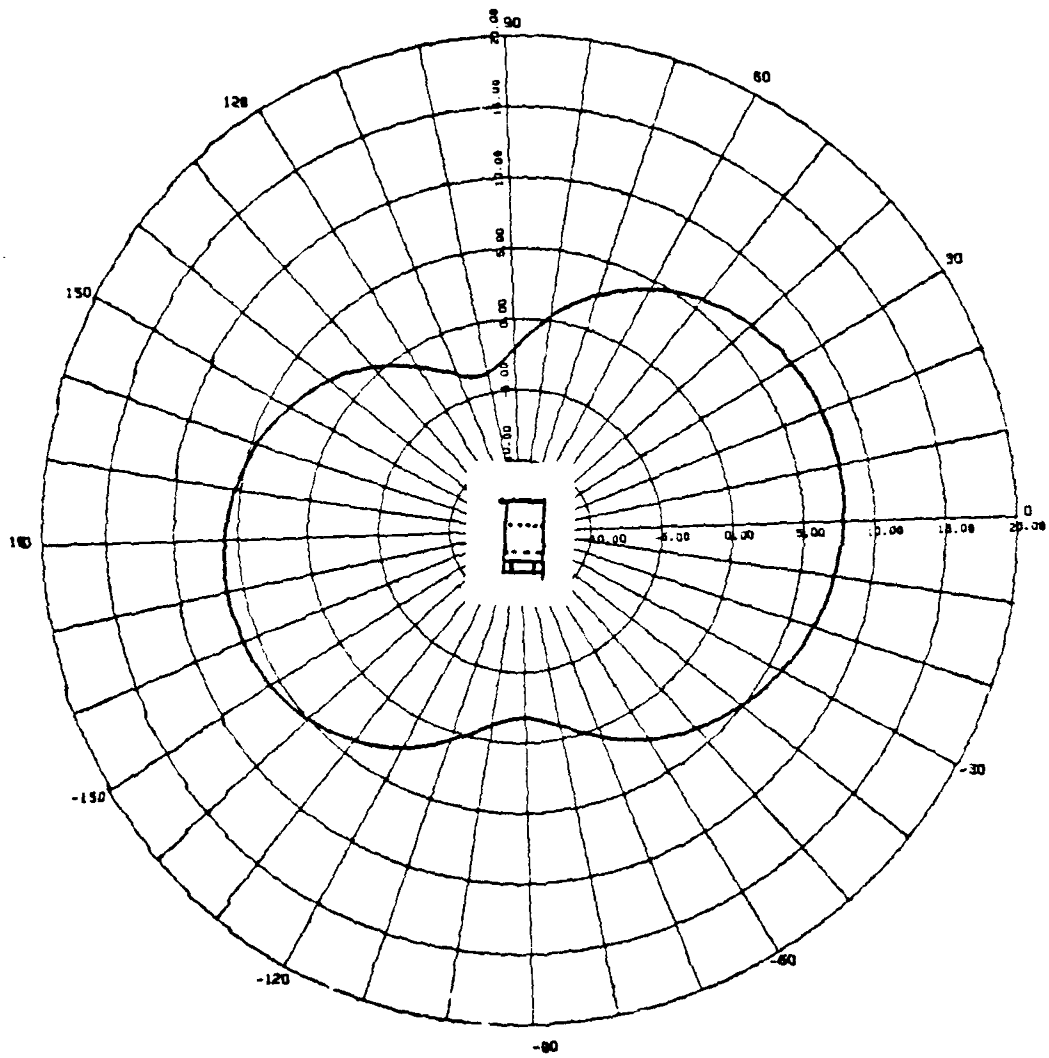
MRC-109 / THETA / PHI = 120

PERFECT GROUND / BASIC / 75 MHZ



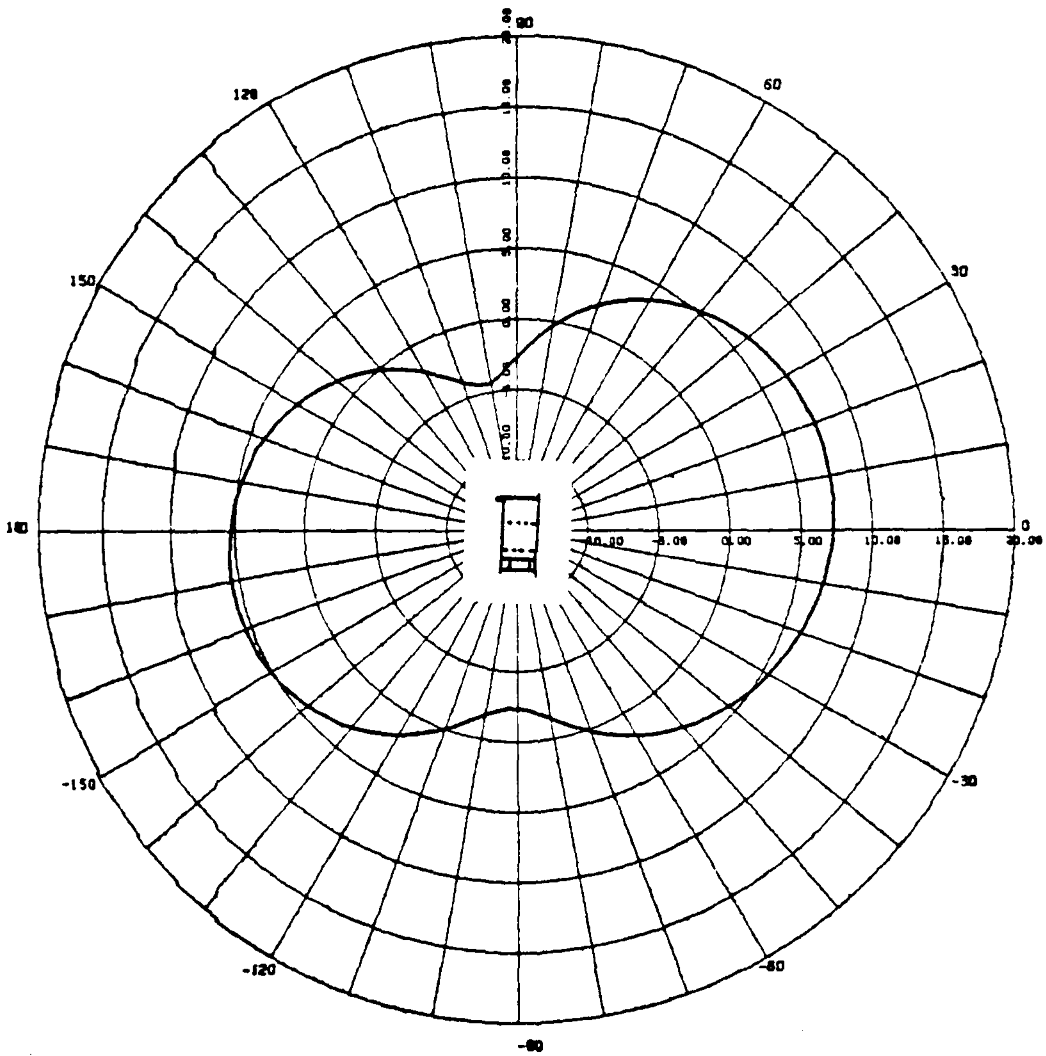
MRC-109 / PHI / THETA=90

PERFECT GROUND / JEEP / 30 MHZ



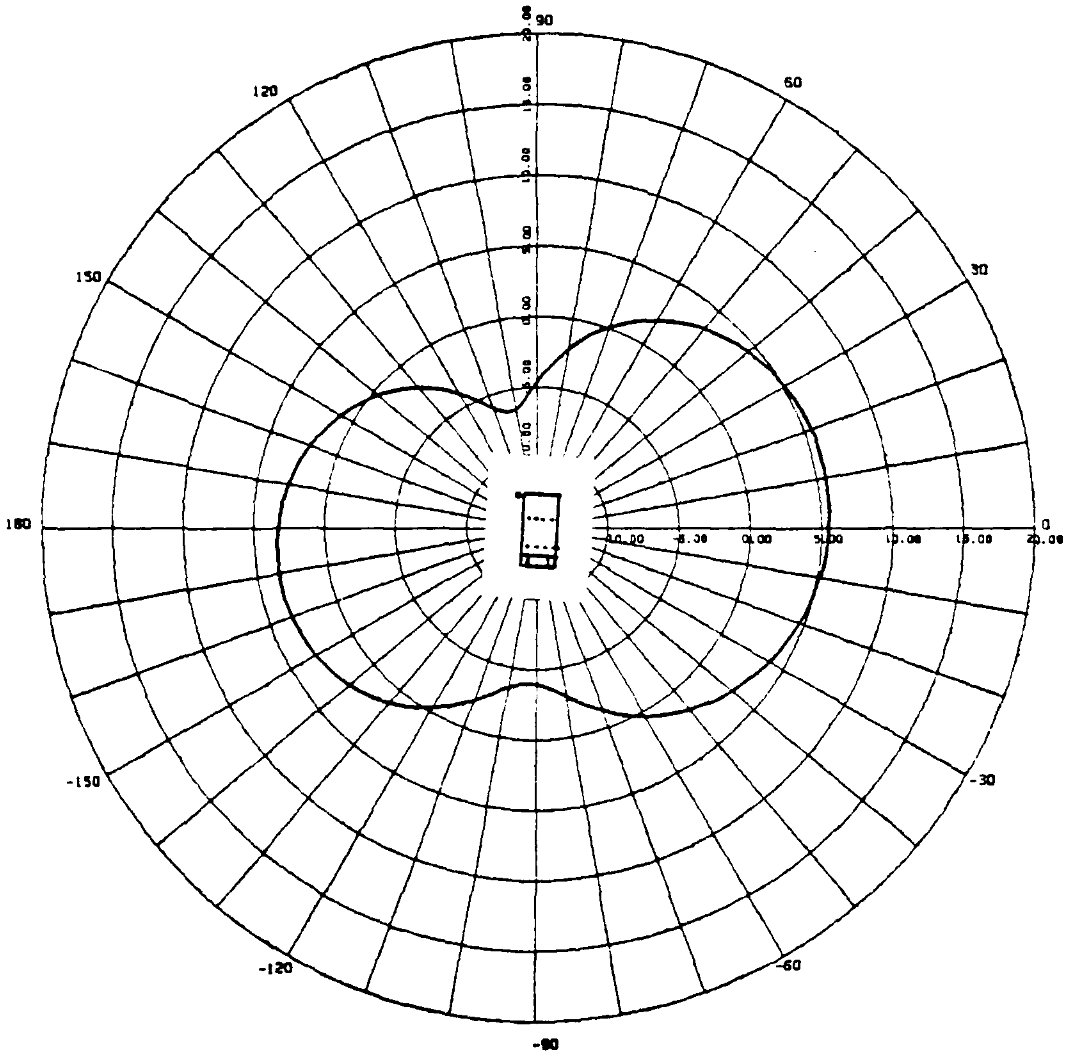
MRC-109 / PHI / THETA= 80

PERFECT GROUND / JEEP / 30 MHZ



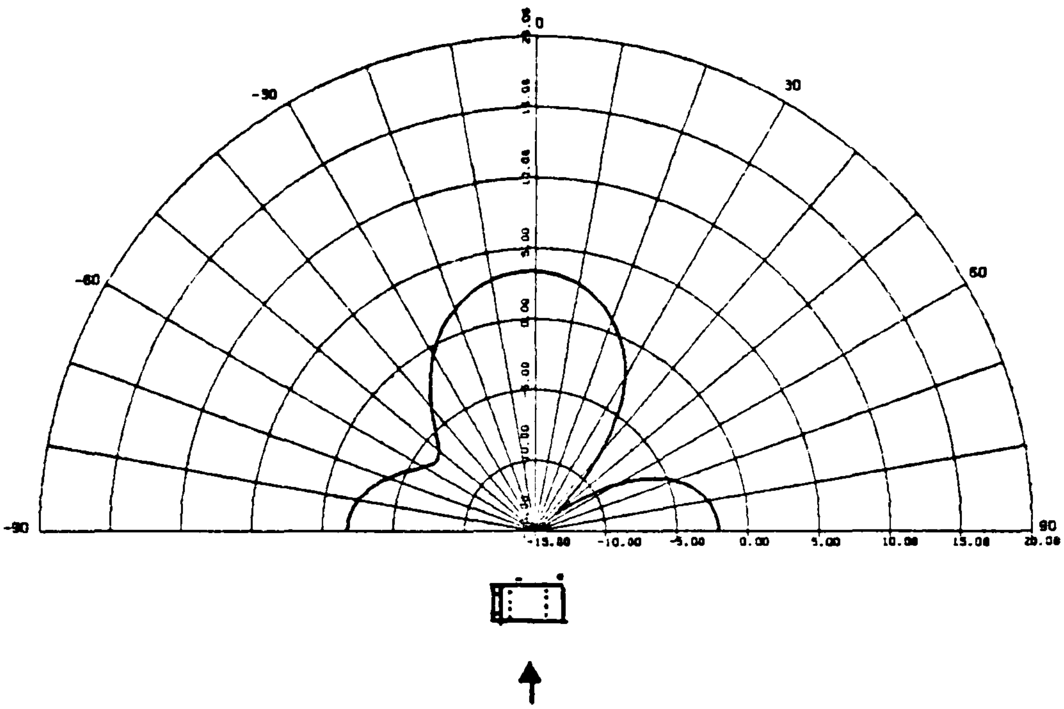
MAC-109 / PHI / THETA= 70

PERFECT GROUND / JEEP / 30 MHZ



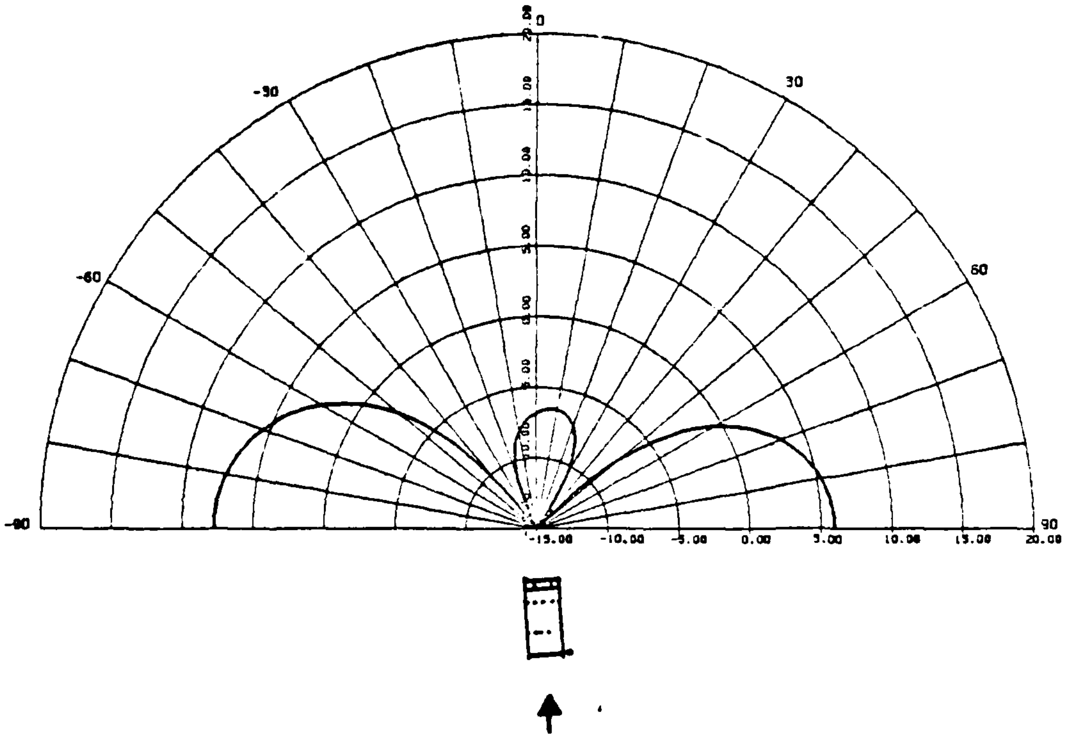
MRC-109 / THETA / PHI = 90

PERFECT GROUND / JEEP / 30 MHZ



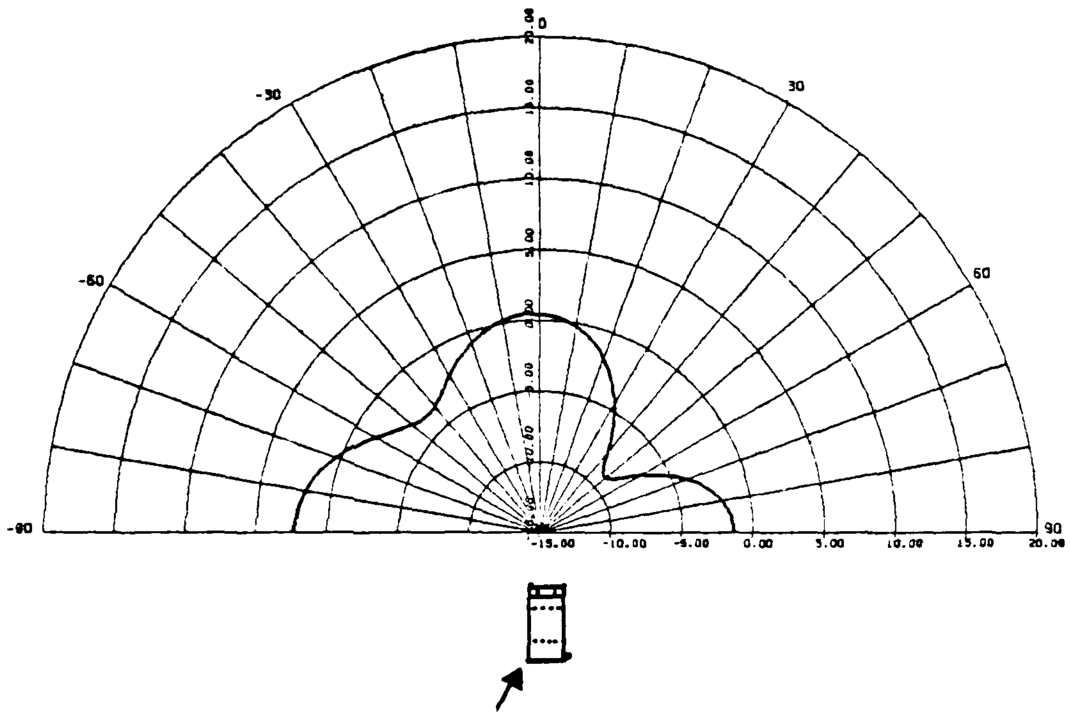
MRC-109 / THETA / PHI = 180

PERFECT GROUND / JEEP / 30 MHZ



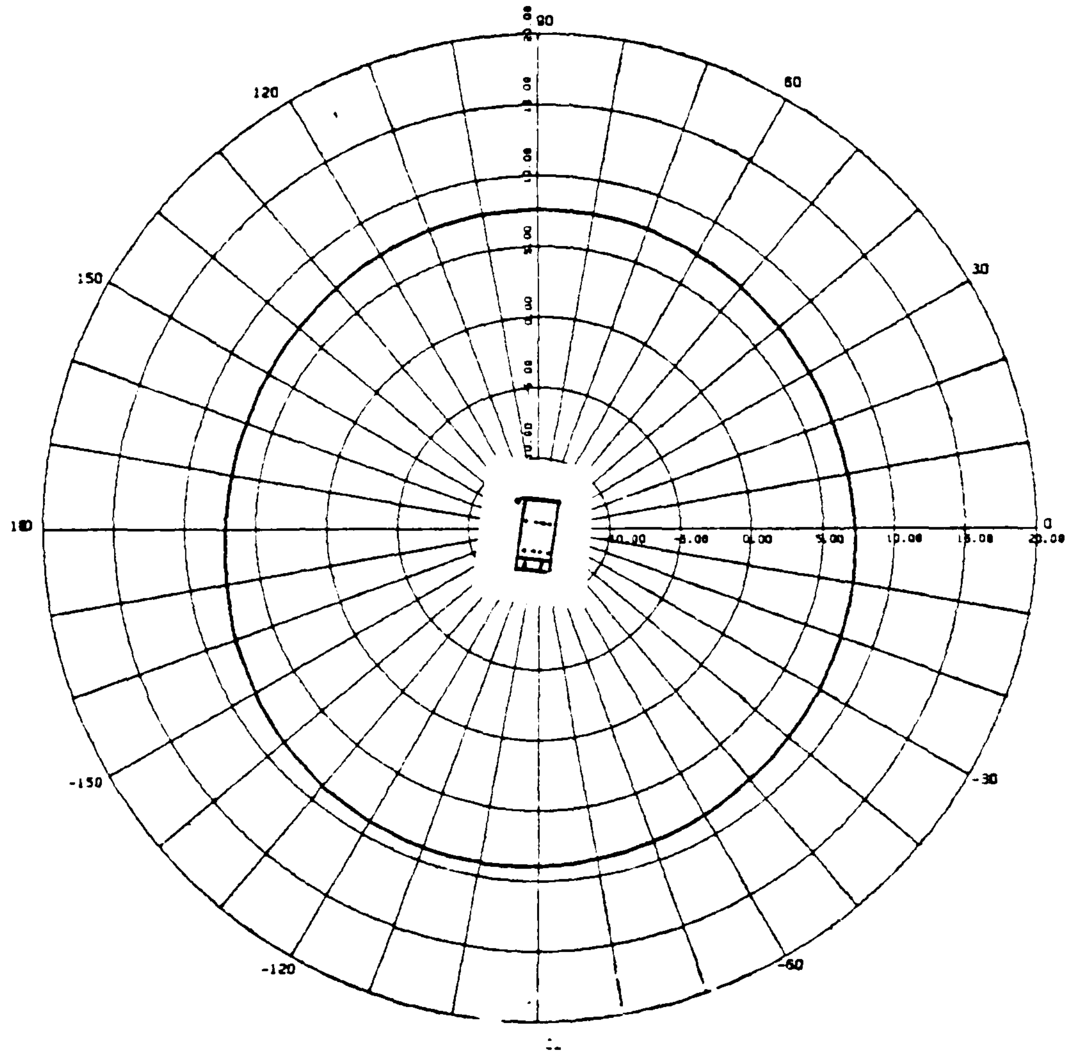
MRC-109 / THETA / PHI = 120

PERFECT GROUND / JEEP / 30 MHZ



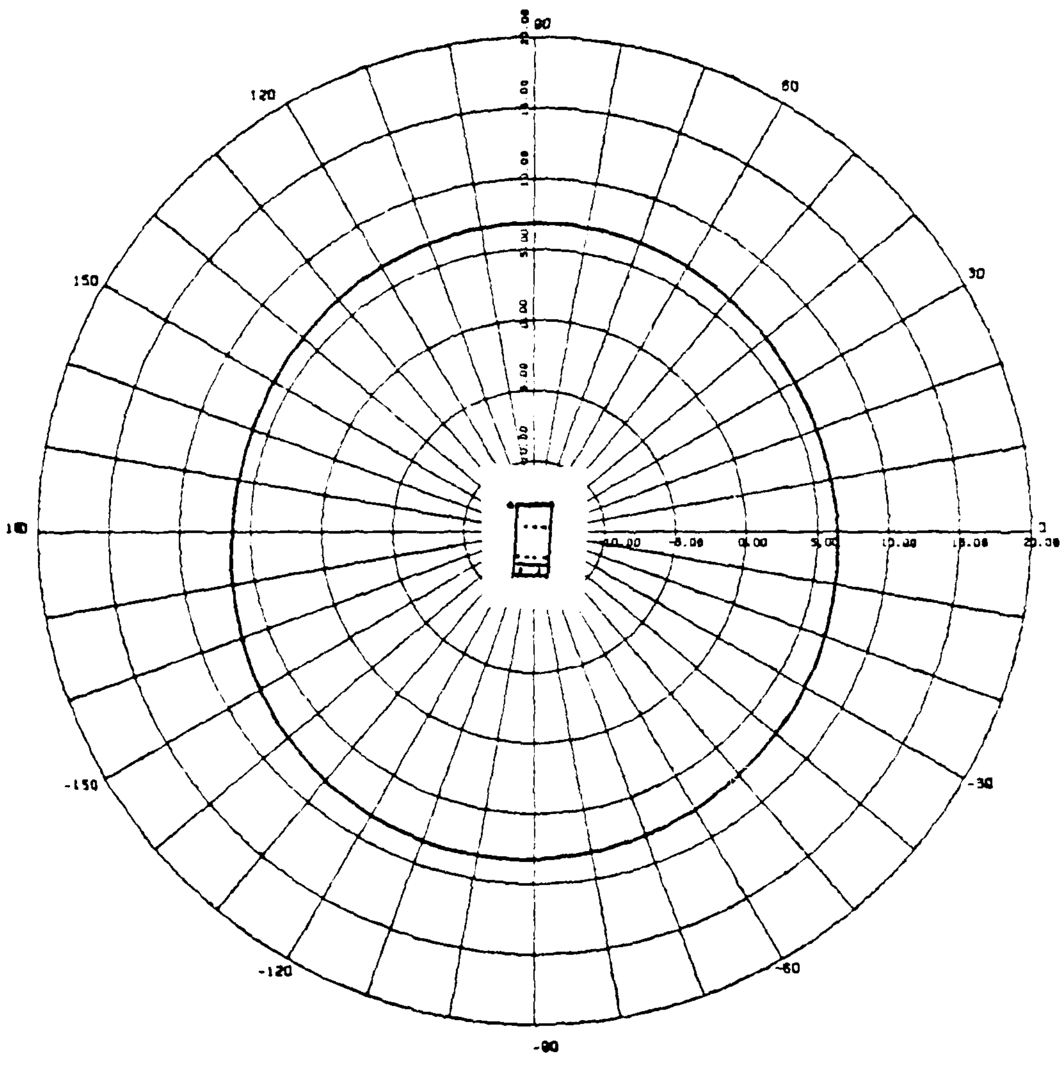
MRC-109 / PHI / THETA=90

PERFECT GROUND / JEEP / 41 MHZ



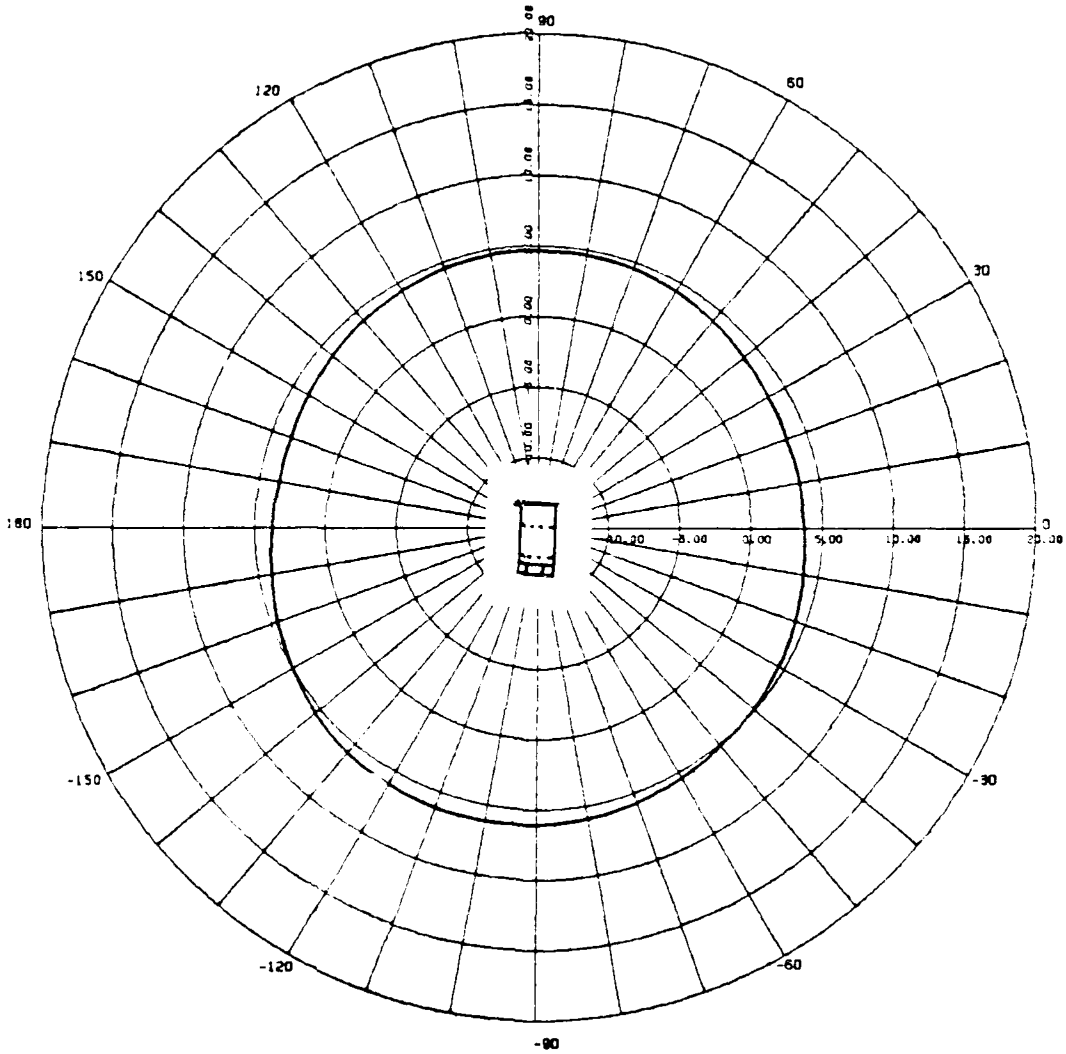
MAC-109 / PHI / THETA= 80

PERFECT GROUND / JEEP / 41 MHZ



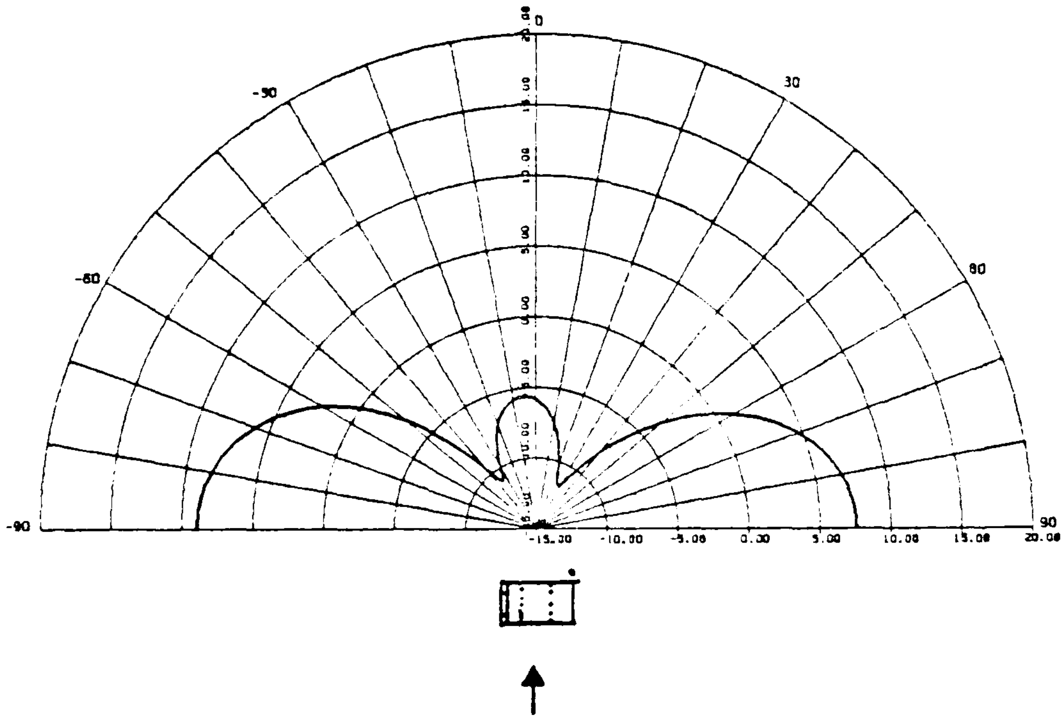
MRC-109 / PHI / THETA= 70

PERFECT GROUND / JEEP / 41 MHZ



MAC-109 / THETA / PHI = 90

PERFECT GROUND / JEEP / 41 MHZ



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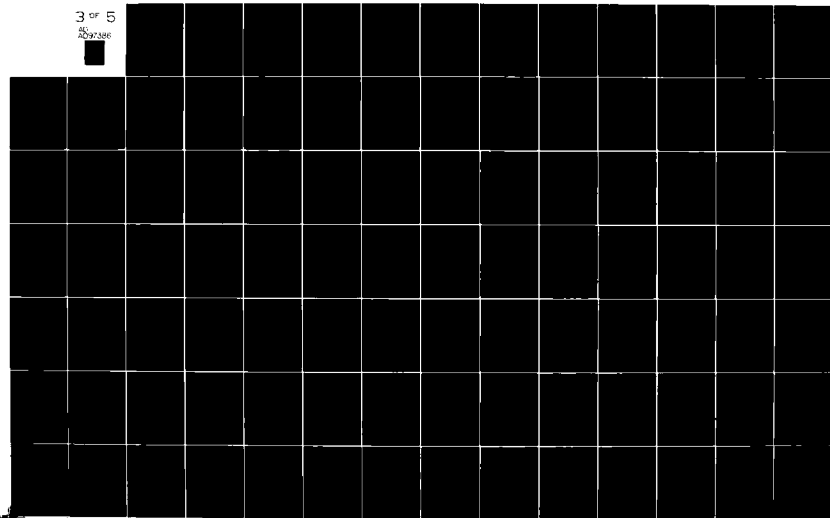
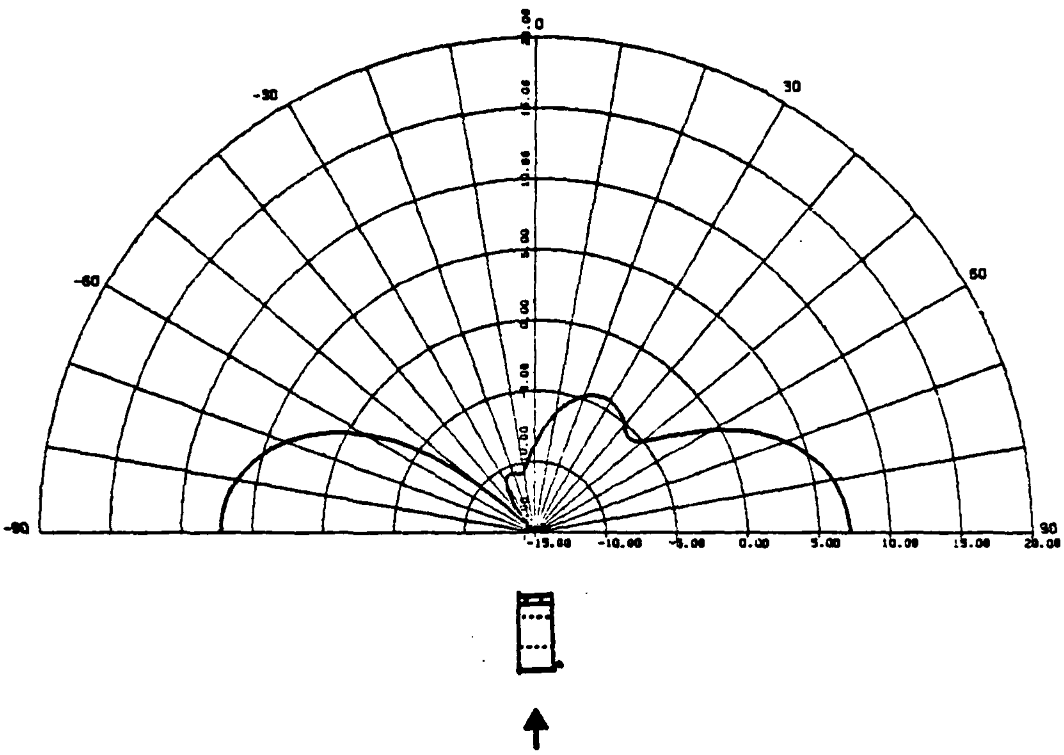


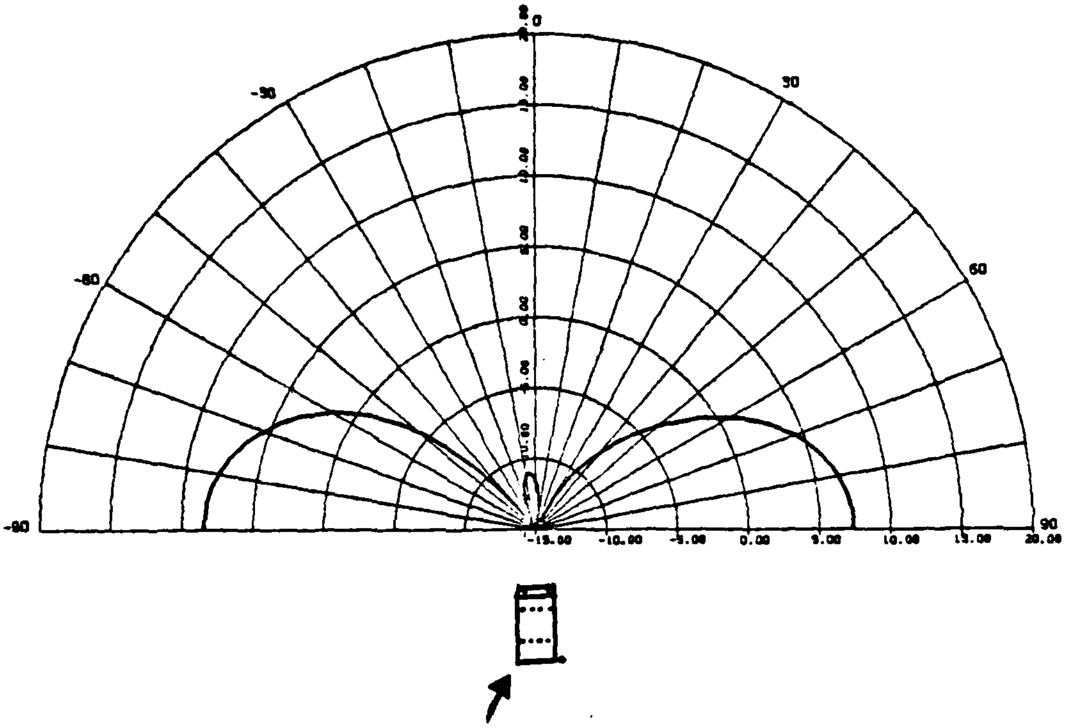
MAC-109 / THETA / PHI = 180

PERFECT GROUND / JEEP / 41 MHZ



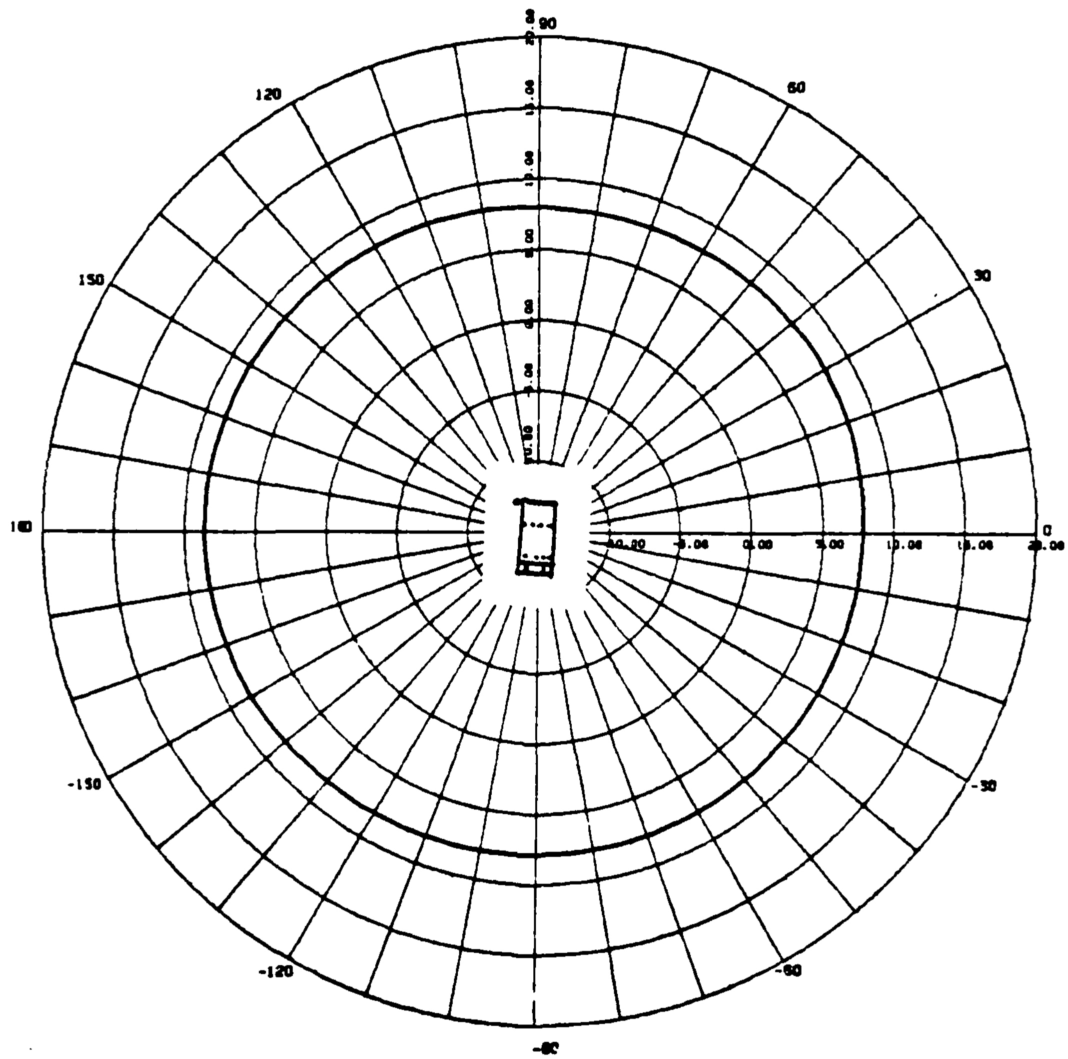
MAC-109 / THETA / PHI = 120

PERFECT GROUND / JEEP / 41 MHZ



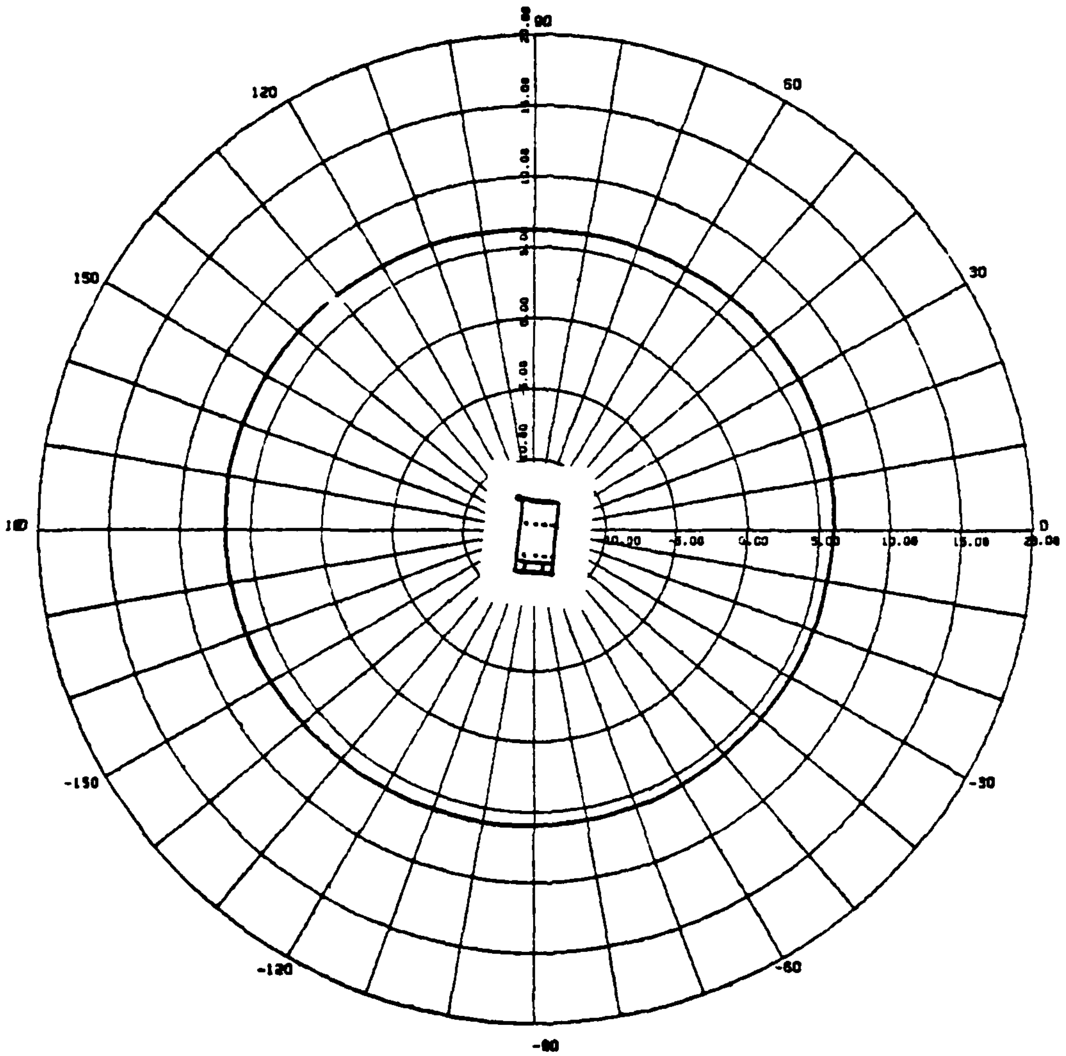
MRC-109 / PHI / THETA=90

PERFECT GROUND / JEEP / 50 MHZ



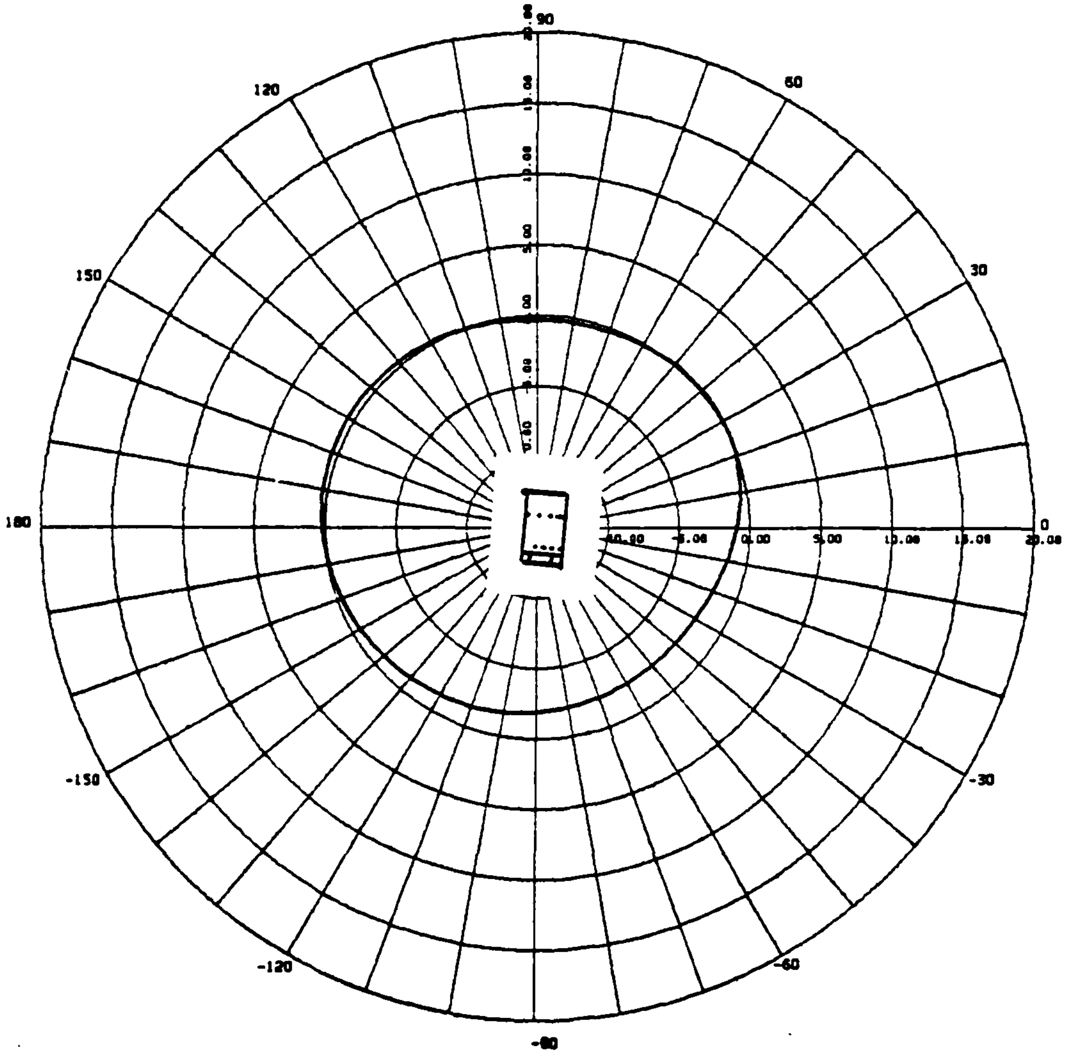
MAC-109 / PHI / THETA= 80

PERFECT GROUND / JEEP / 50 MHZ



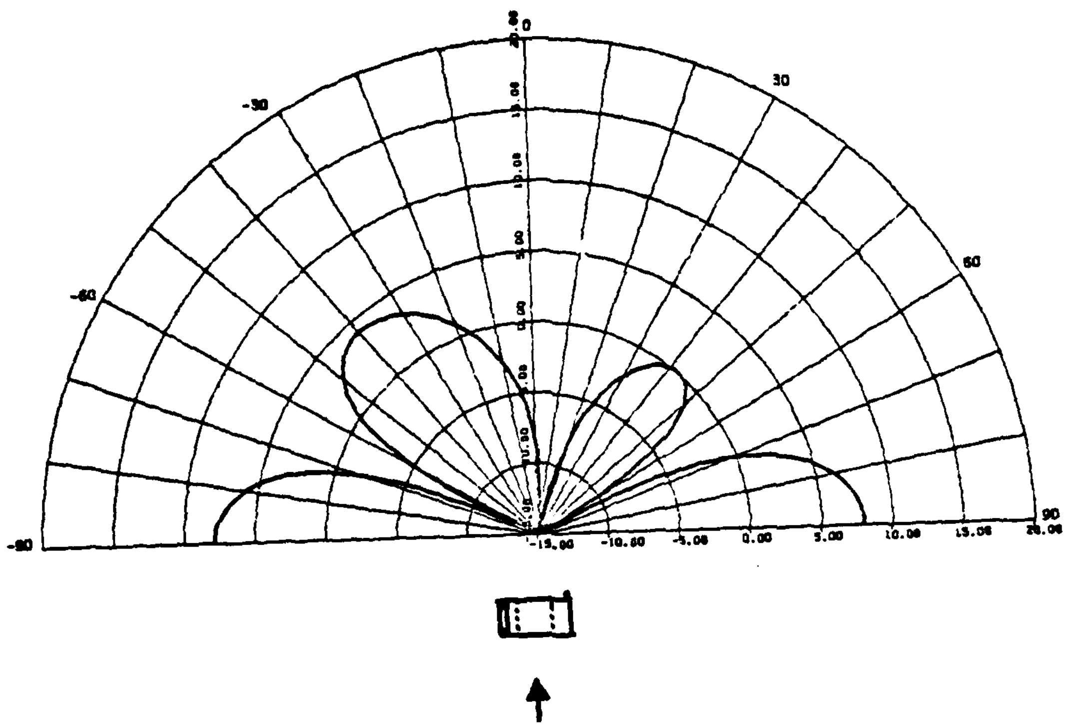
MAC-109 / PHI / THETA= 70

PERFECT GROUND / JEEP / 50 MHZ



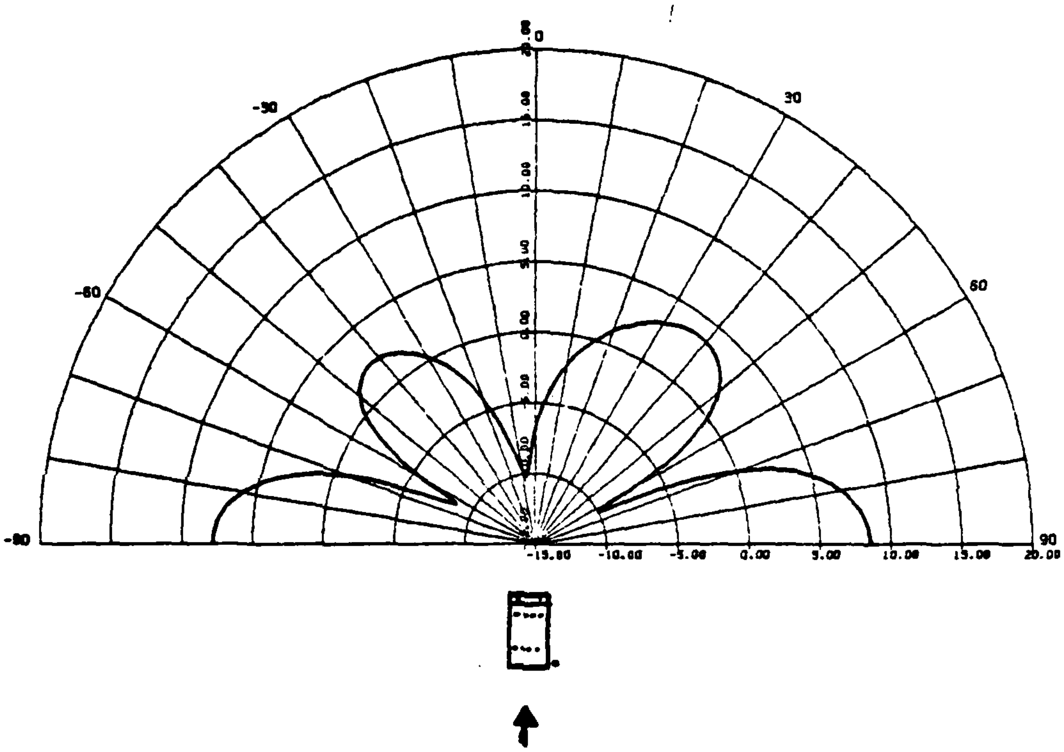
MAC-109 / THETA / PHI = 90

PERFECT GROUND / JEEP / 50 MHZ



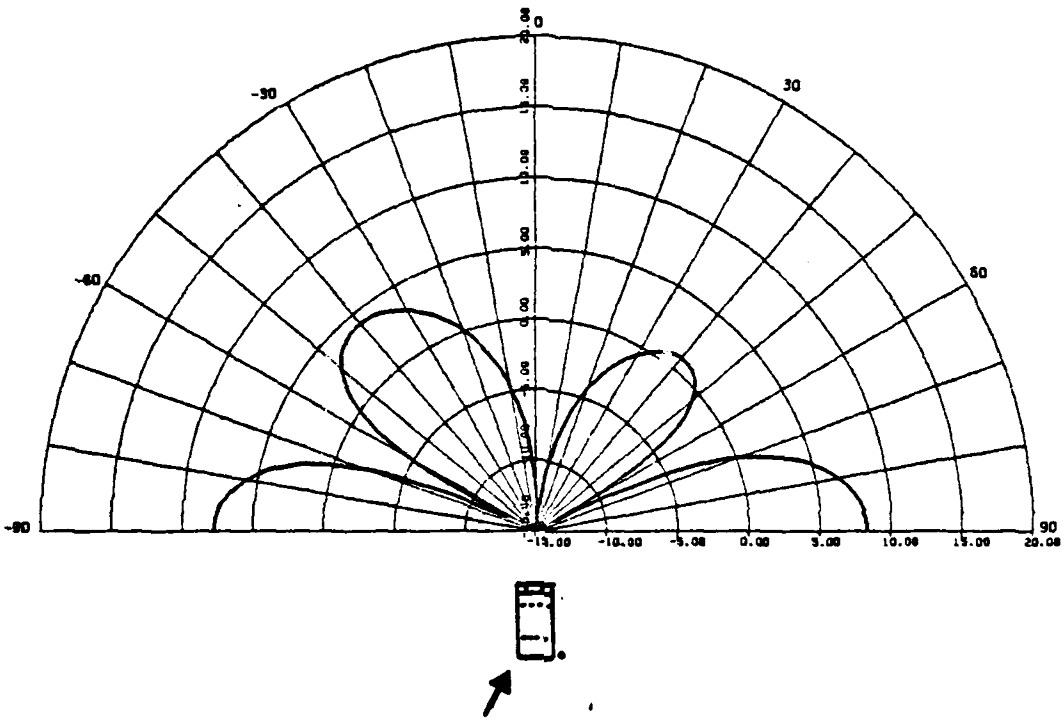
MAC-109 / THETA / PHI = 180

PERFECT GROUND / JEEP / 50 MHZ



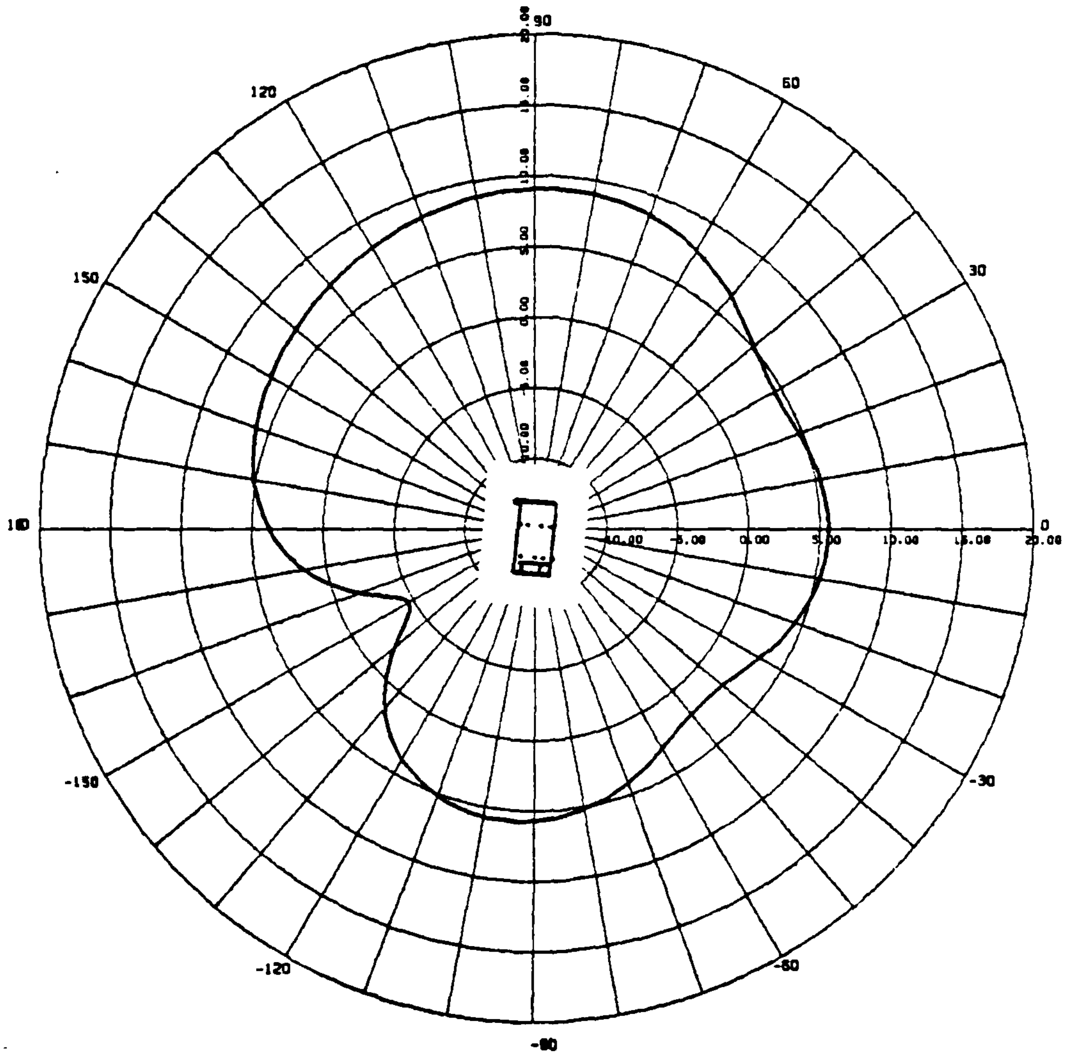
MRC-109 / THETA / PHI = 120

PERFECT GROUND / JEEP / 50 MHZ



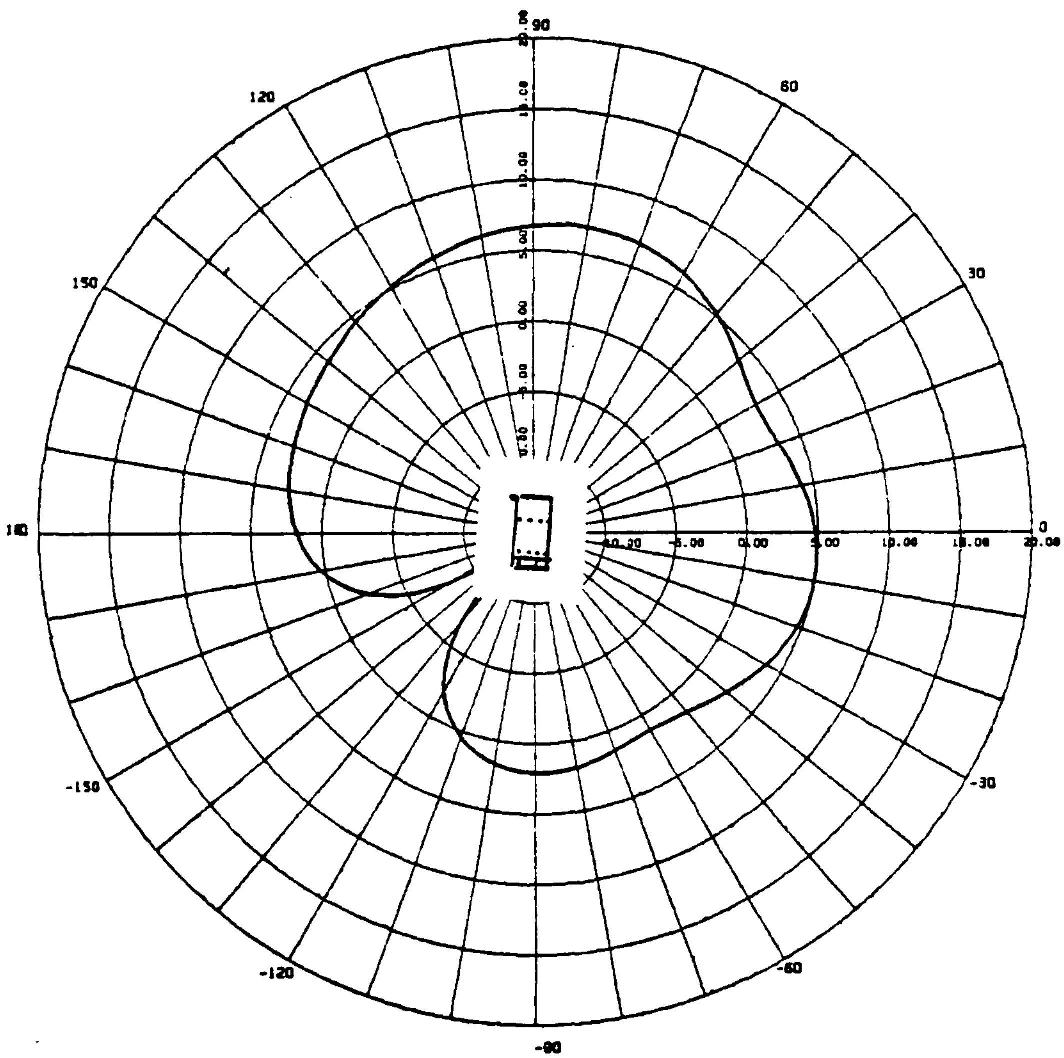
MAC-109 / PHI / THETA=90

PERFECT GROUND / JEEP / 75 MHZ



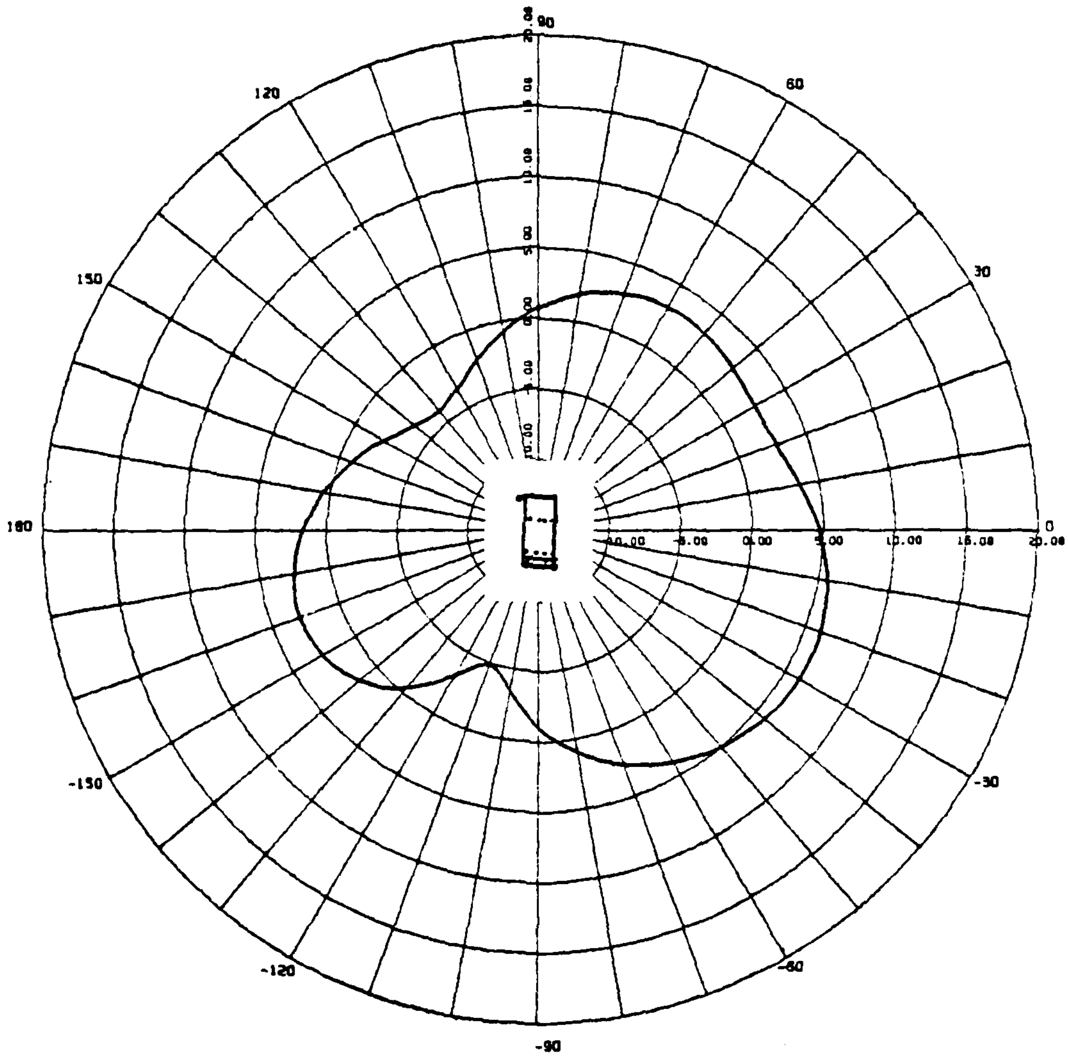
MRC-109 / PHI / THETA= 80

PERFECT GROUND / JEEP / 75 MHZ



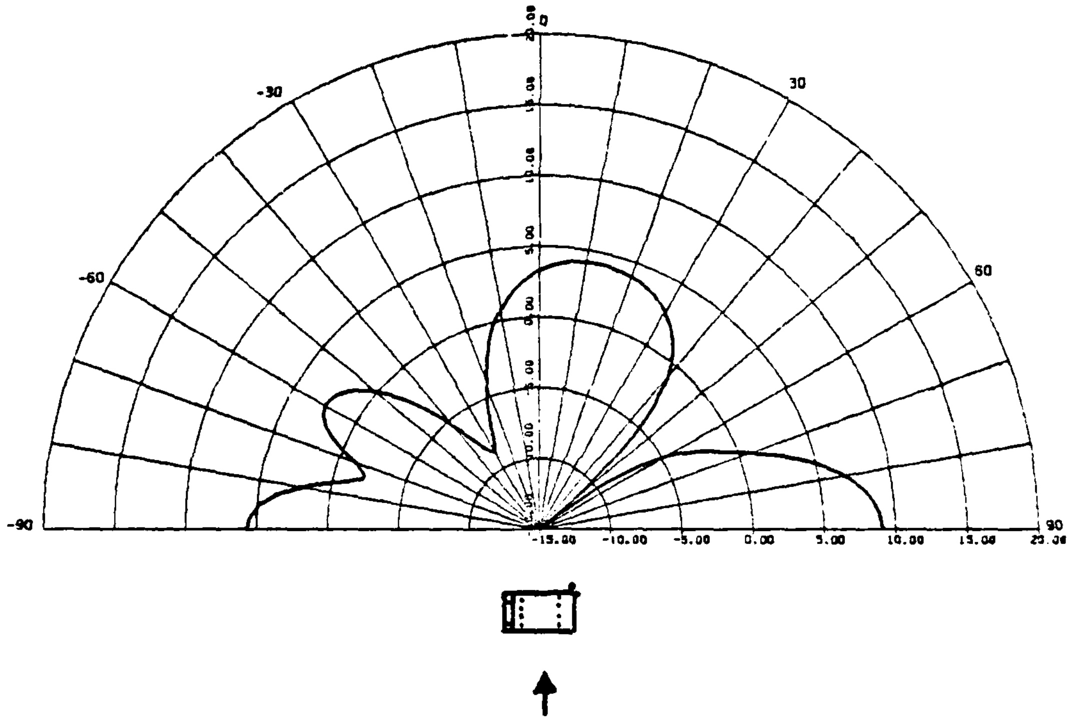
MAC-109 / PHI / THETA= 70

PERFECT GROUND / JEEP / 75 MHZ



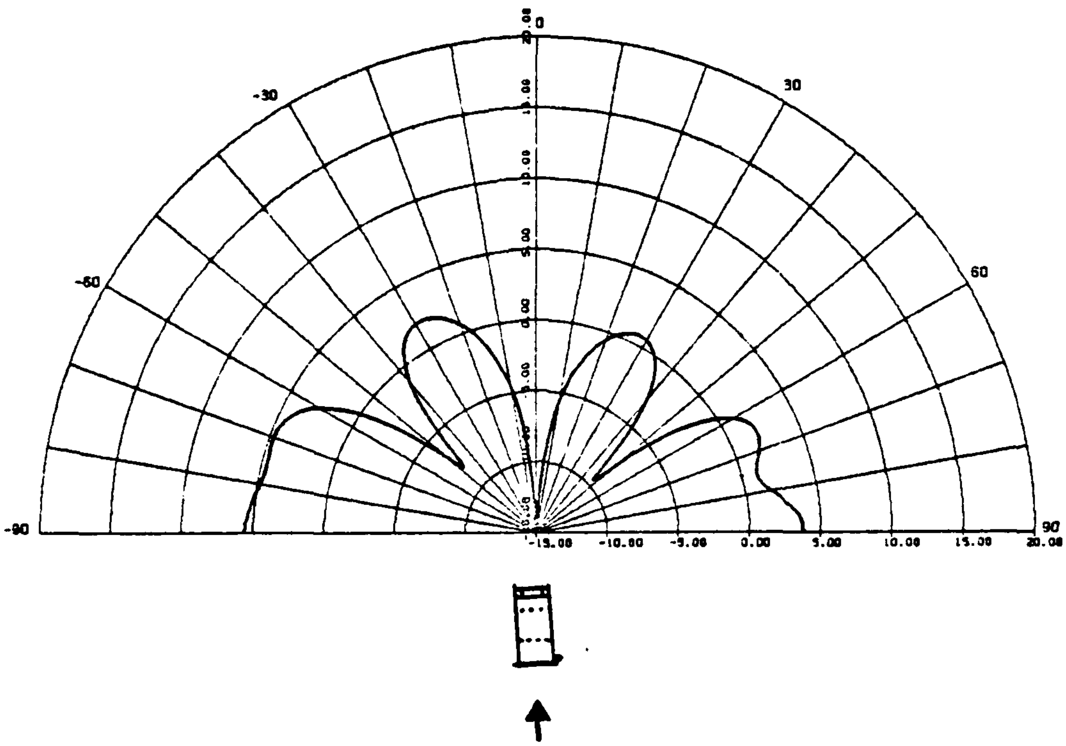
MRC-109 / THETA / PHI = 90

PERFECT GROUND / JEEP / 75 MHZ



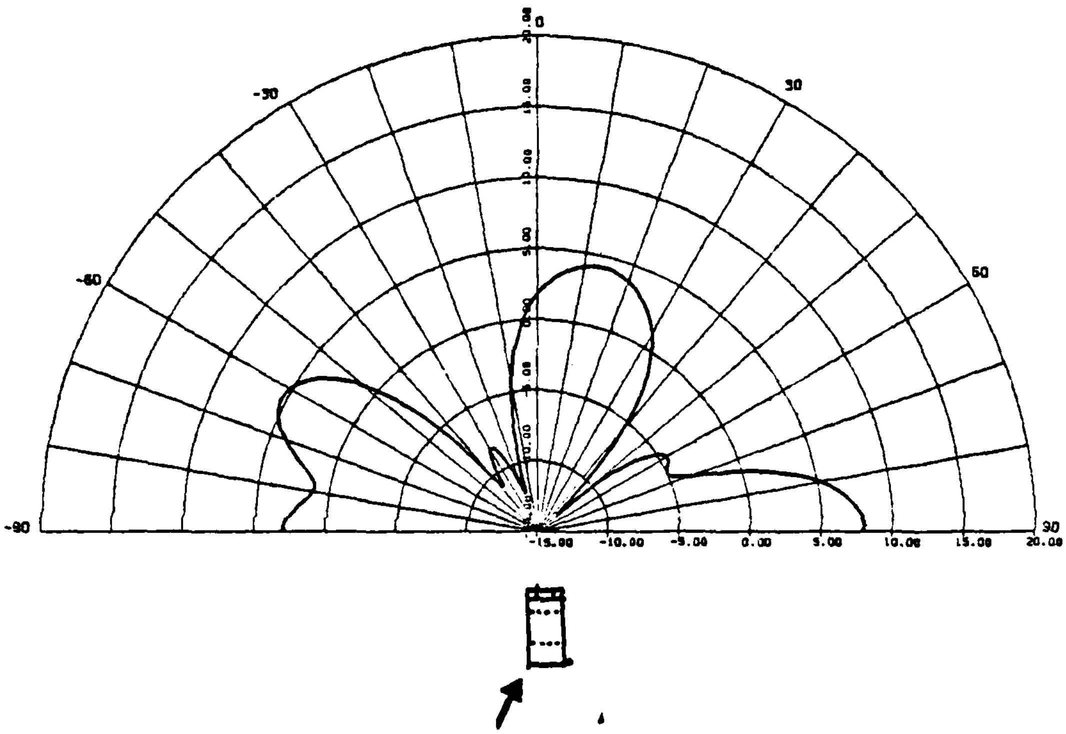
MAC-109 / THETA / PHI = 180

PERFECT GROUND / JEEP / 75 MHZ



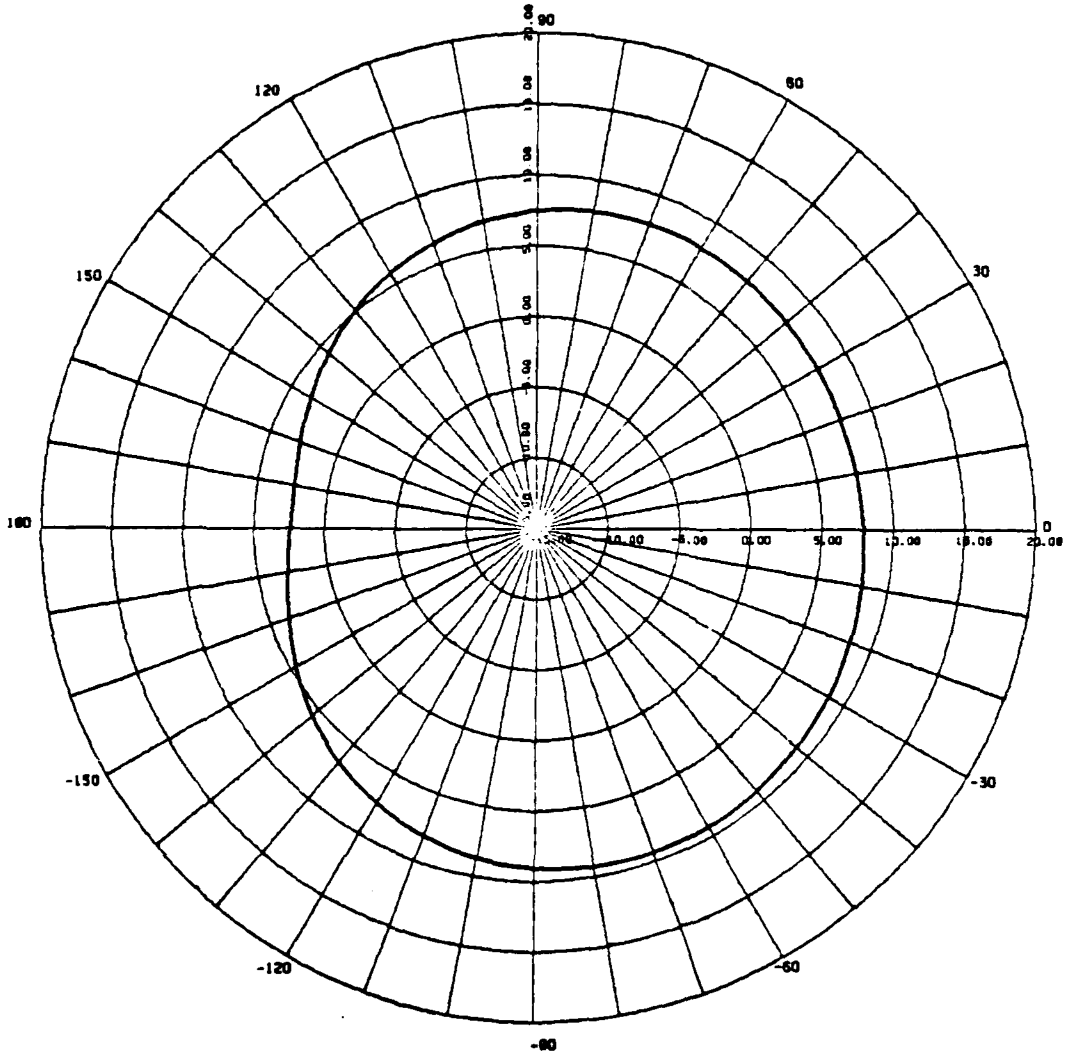
MRC-109 / THETA / PHI = 120

PERFECT GROUND / JEEP / 75 MHZ



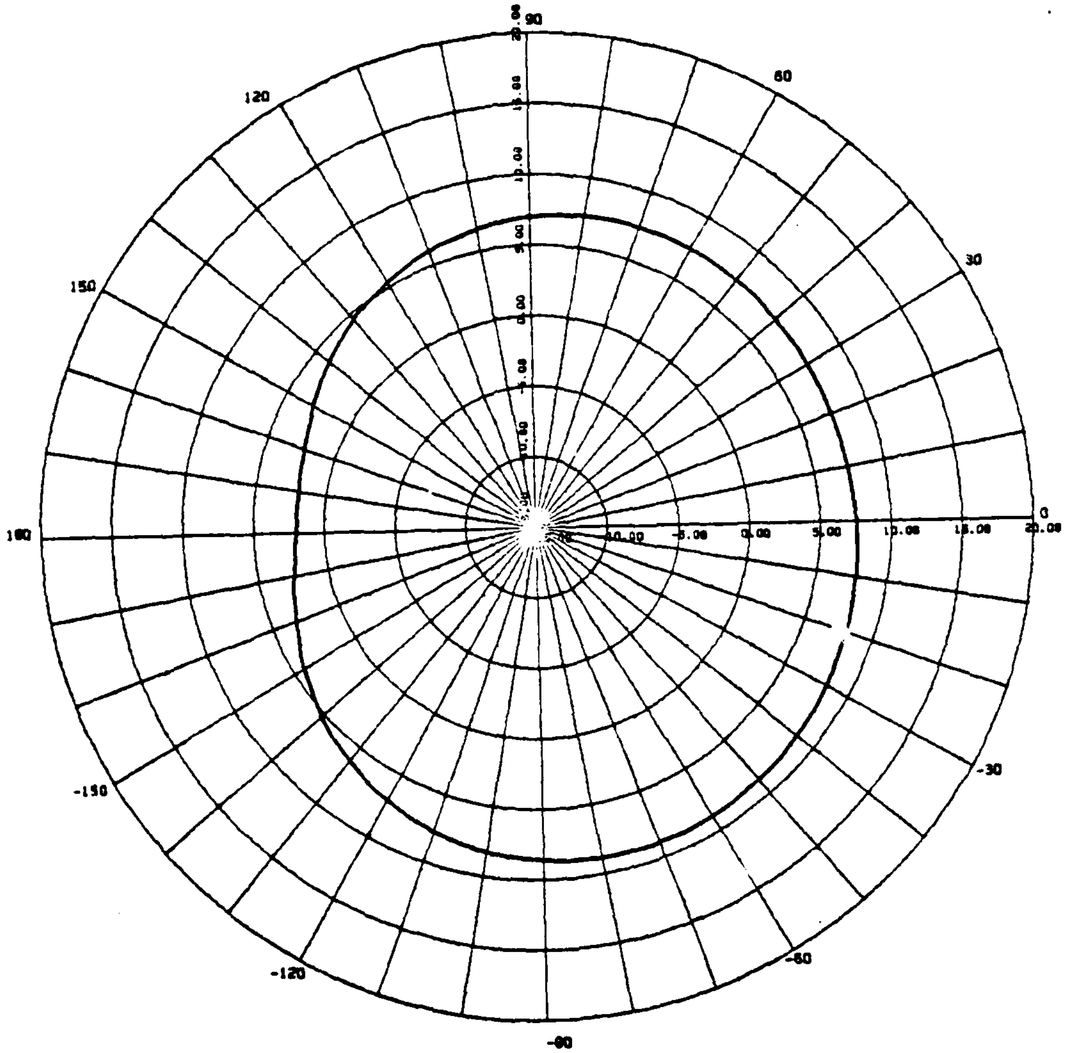
MAC-109 / PHI / THETA=90

PER GRND / JEEP & TRLR / 30 MHZ



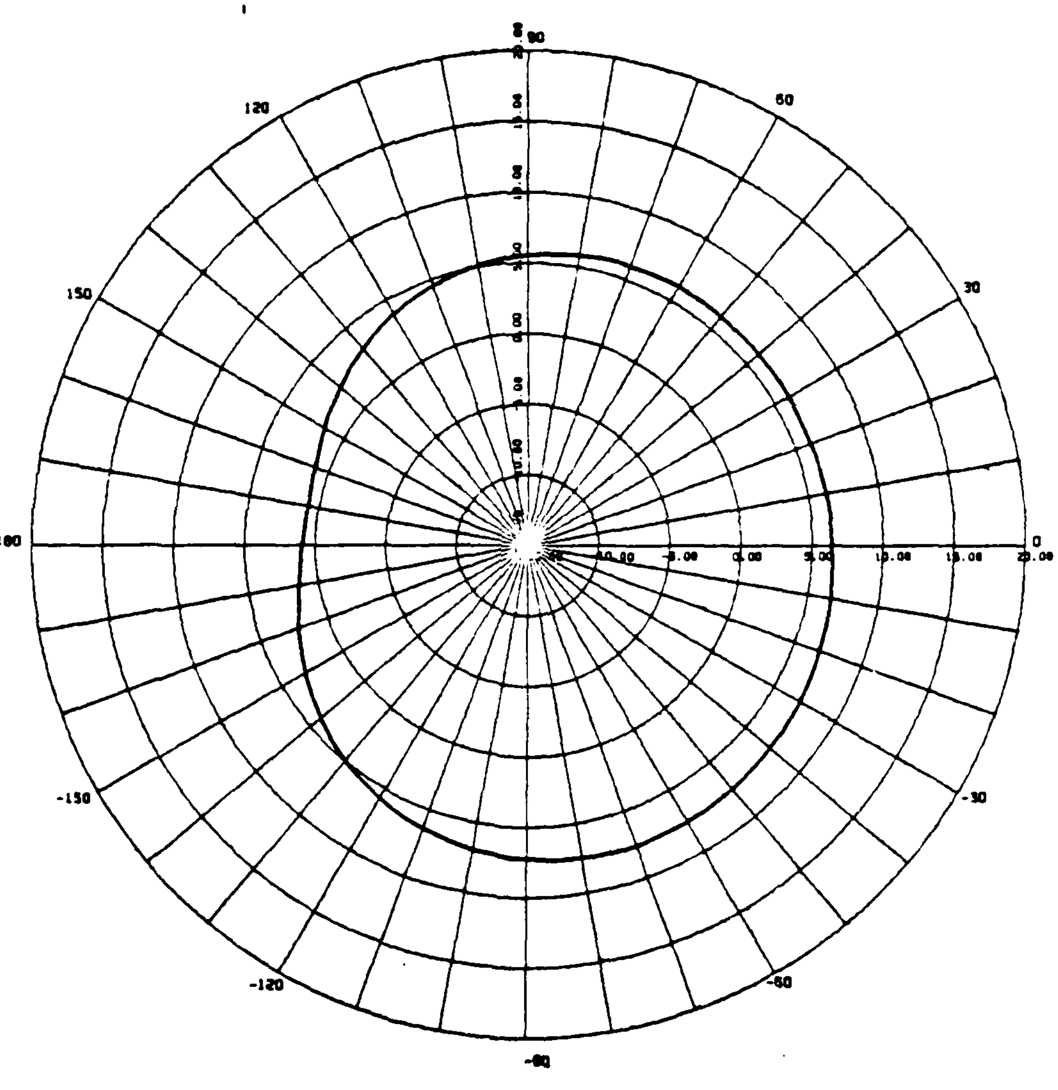
MAC-109 / PHI / THETA=80

PER GRND / JEEP & TALA / 30 MHZ



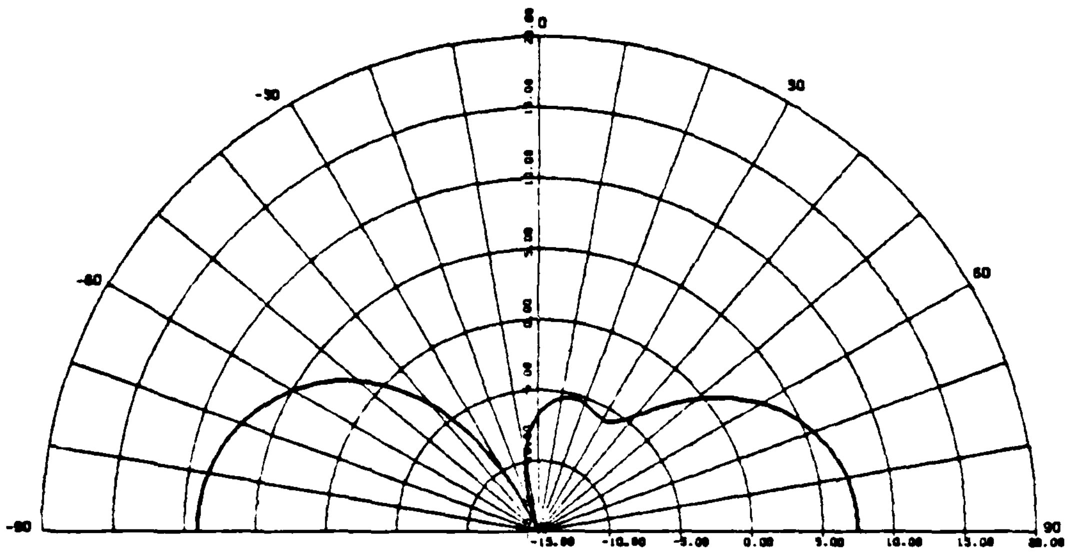
MAC-109 / PHI / THETA=70

PER GRND / JEEP & TRLR / 30 MHZ



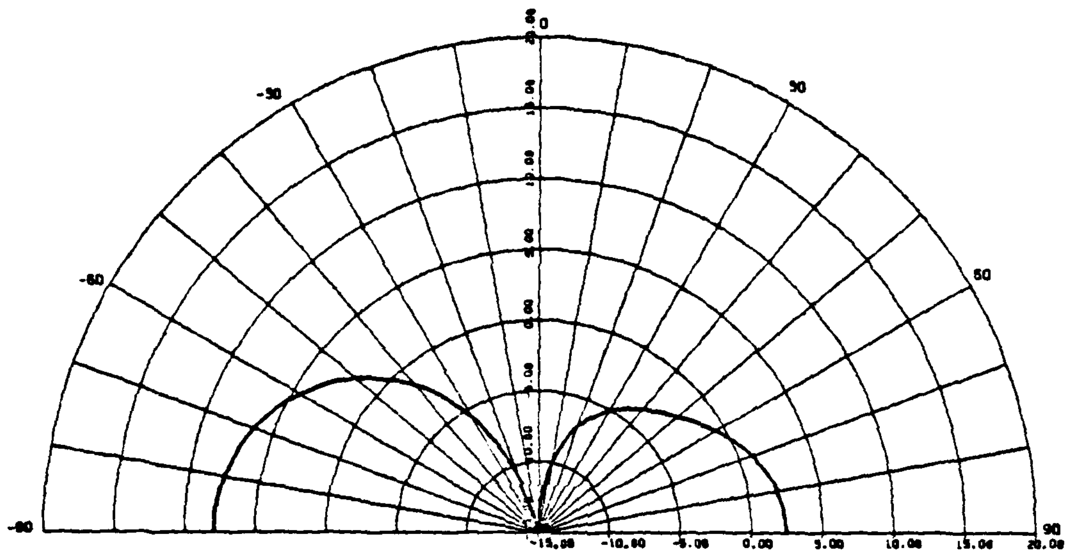
MAC-109 / THETA / PHI=90

PER GRND / JEEP & TRLR / 30 MHZ



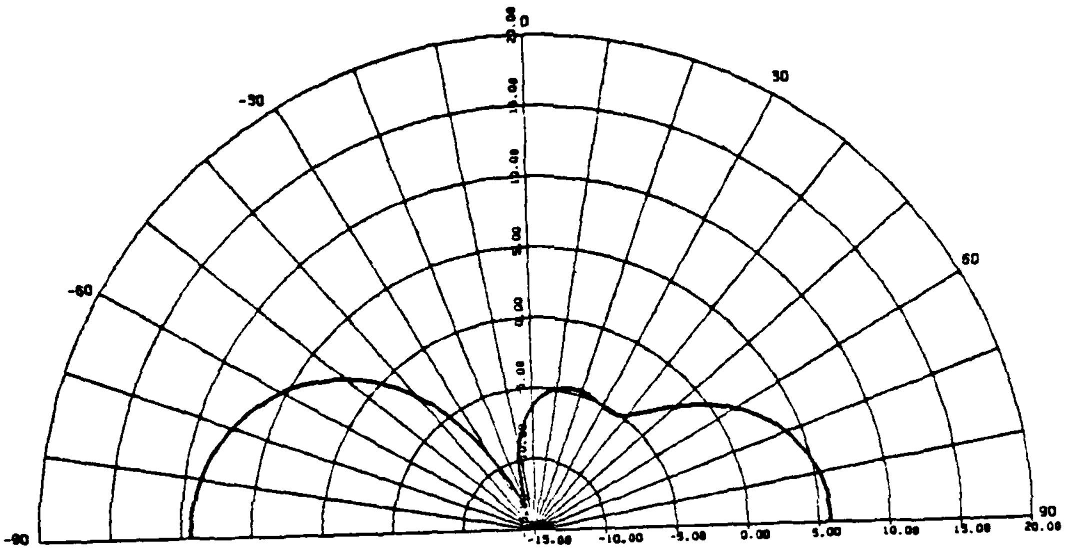
MAC-109 / THETA / PHI=180

PER GRND / JEEP & TALA / 30 MHZ



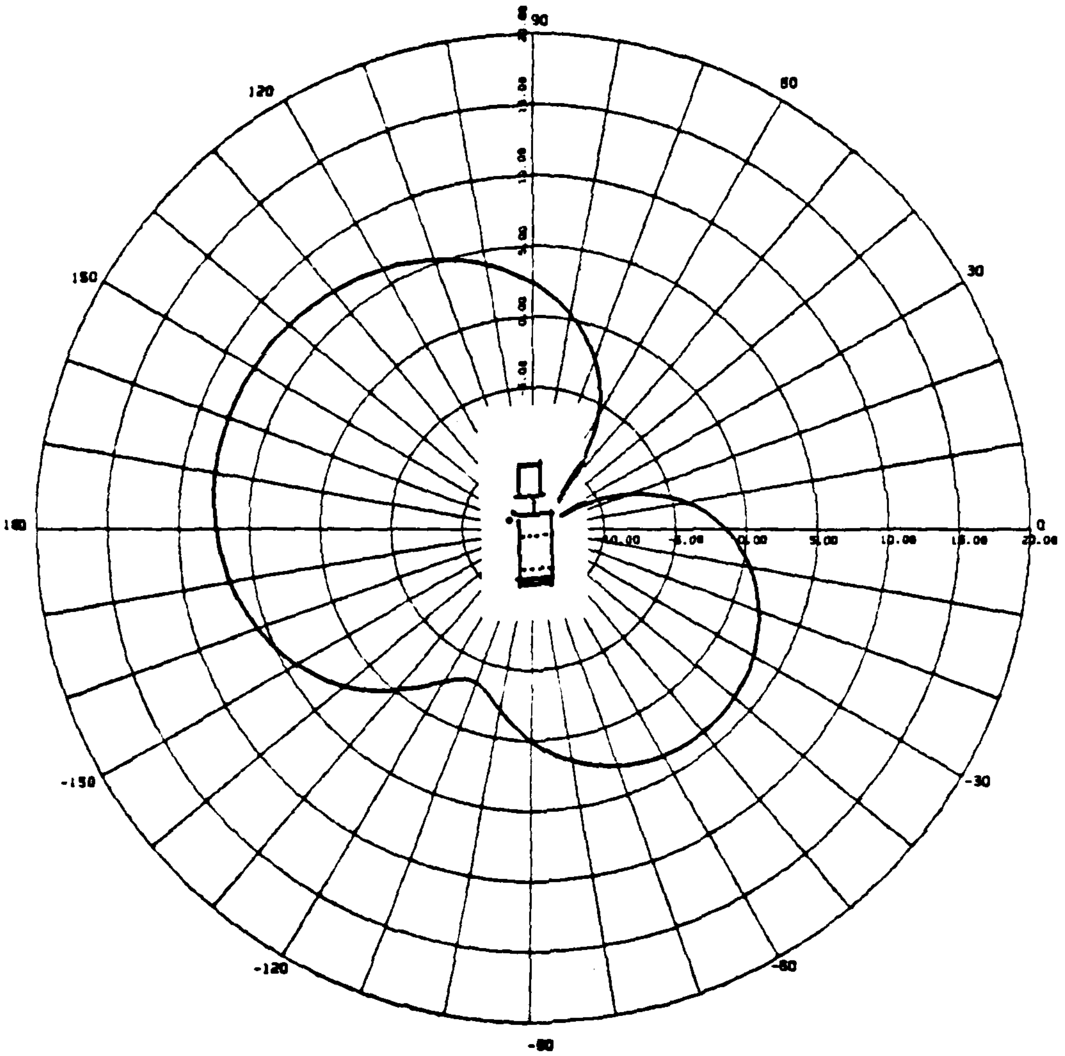
MAC-109 / THETA / PHI=120

PER GRND / JEEP & TRLR / 30 MHZ



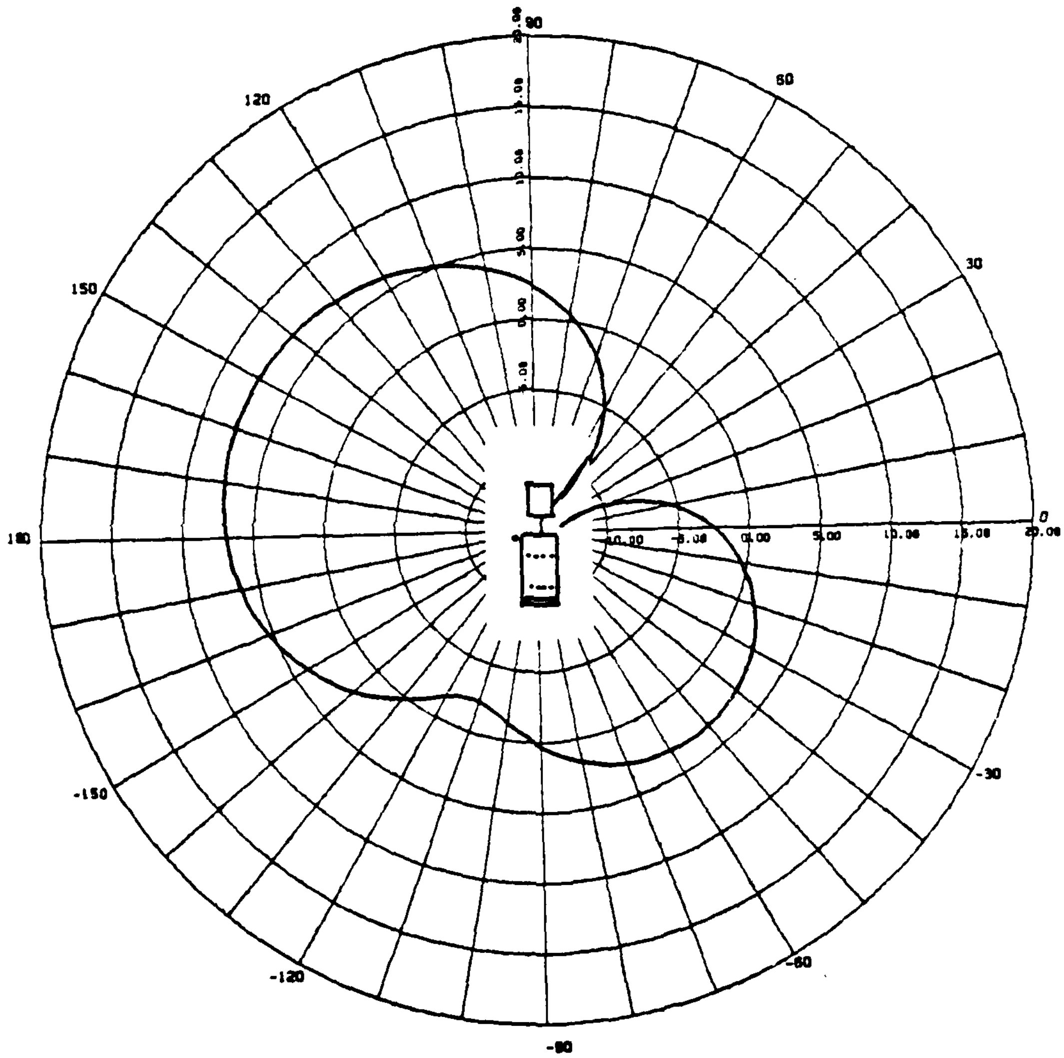
MAC-109 / PHI / THETA=90

PER GRND / JEEP & TALA / 41 MHZ



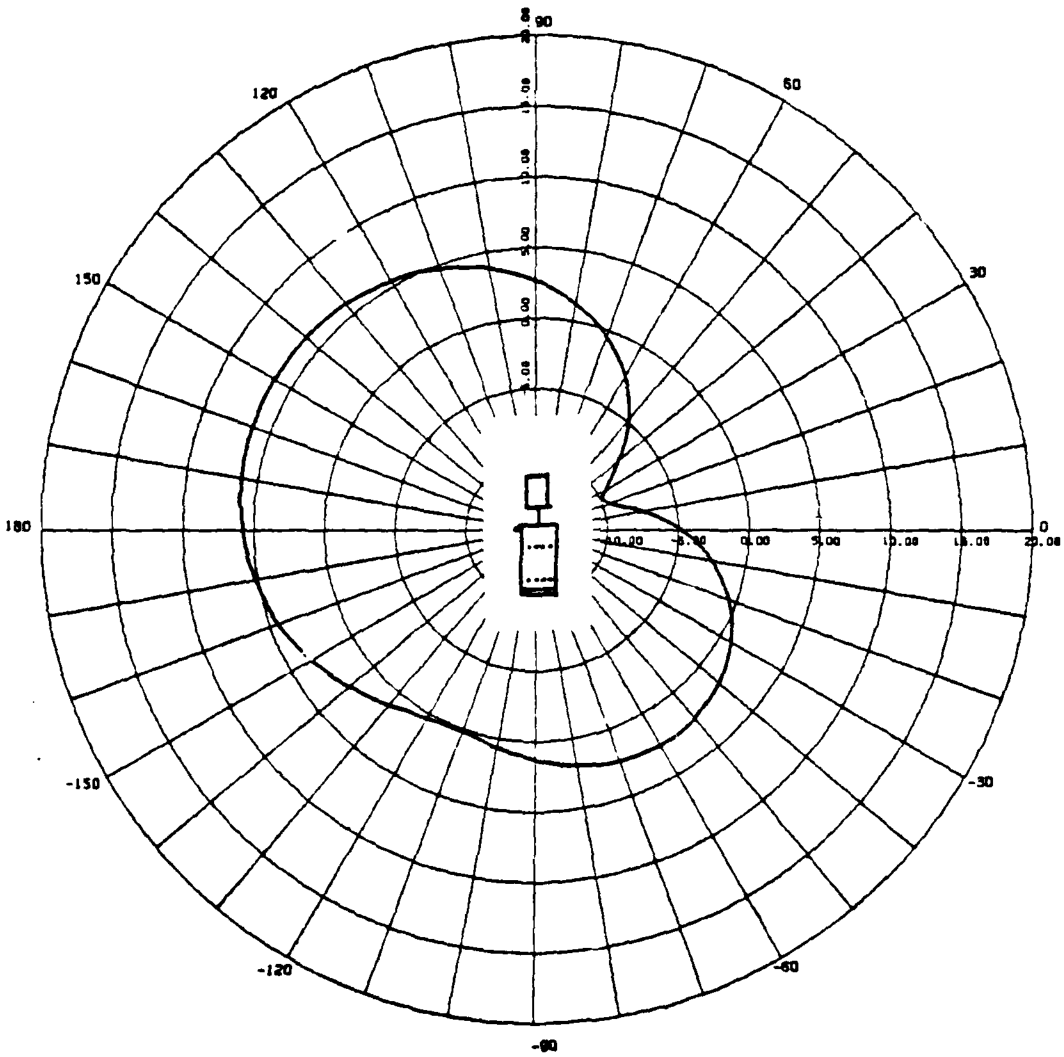
MAC-109 / PHI / THETA=80

PER GAND / JEEP & TALA / 41 MHZ



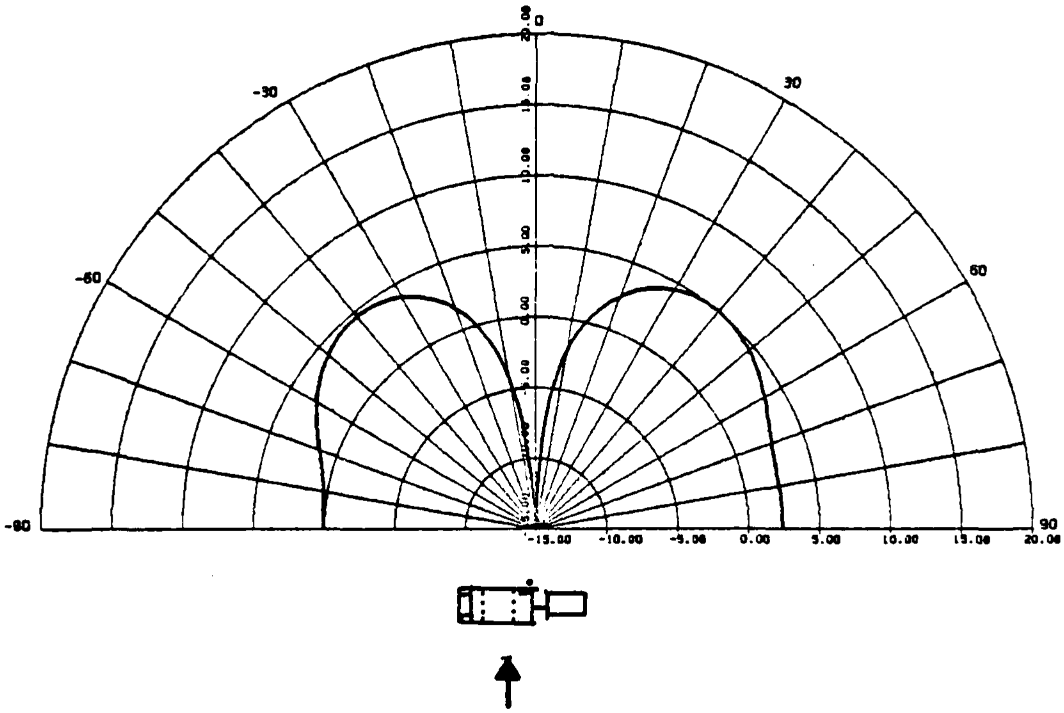
MAC-109 / PHI / THETA=70

PER GRND / JEEP & TRLR / 41 MHZ



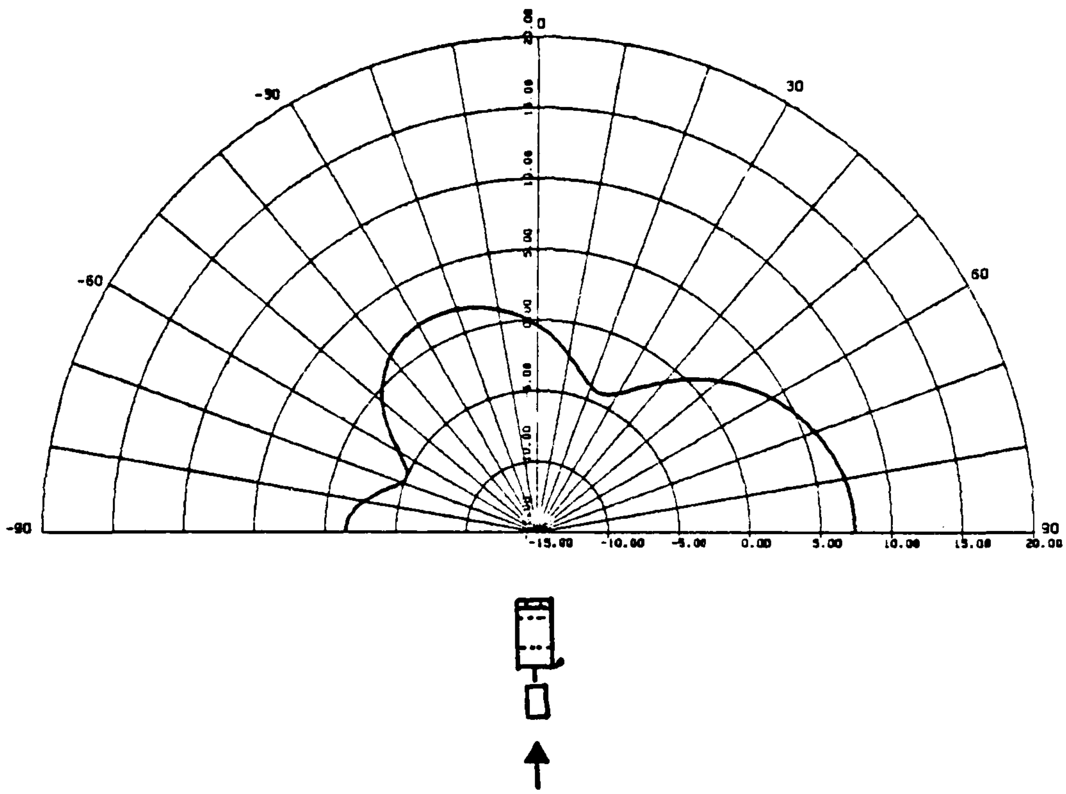
MRC-109 / THETA / PHI=90

PER GRND / JEEP & TRLR / 41 MHZ



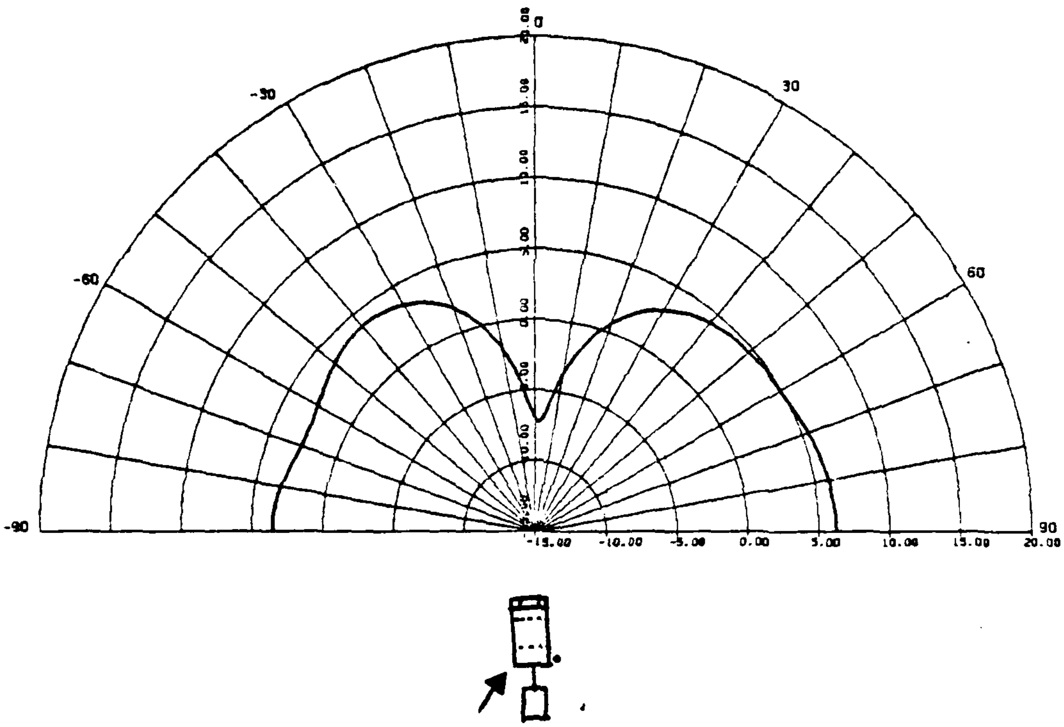
MRC-109 / THETA / PHI=180

PER GRND / JEEP & TRLR / 41 MHZ



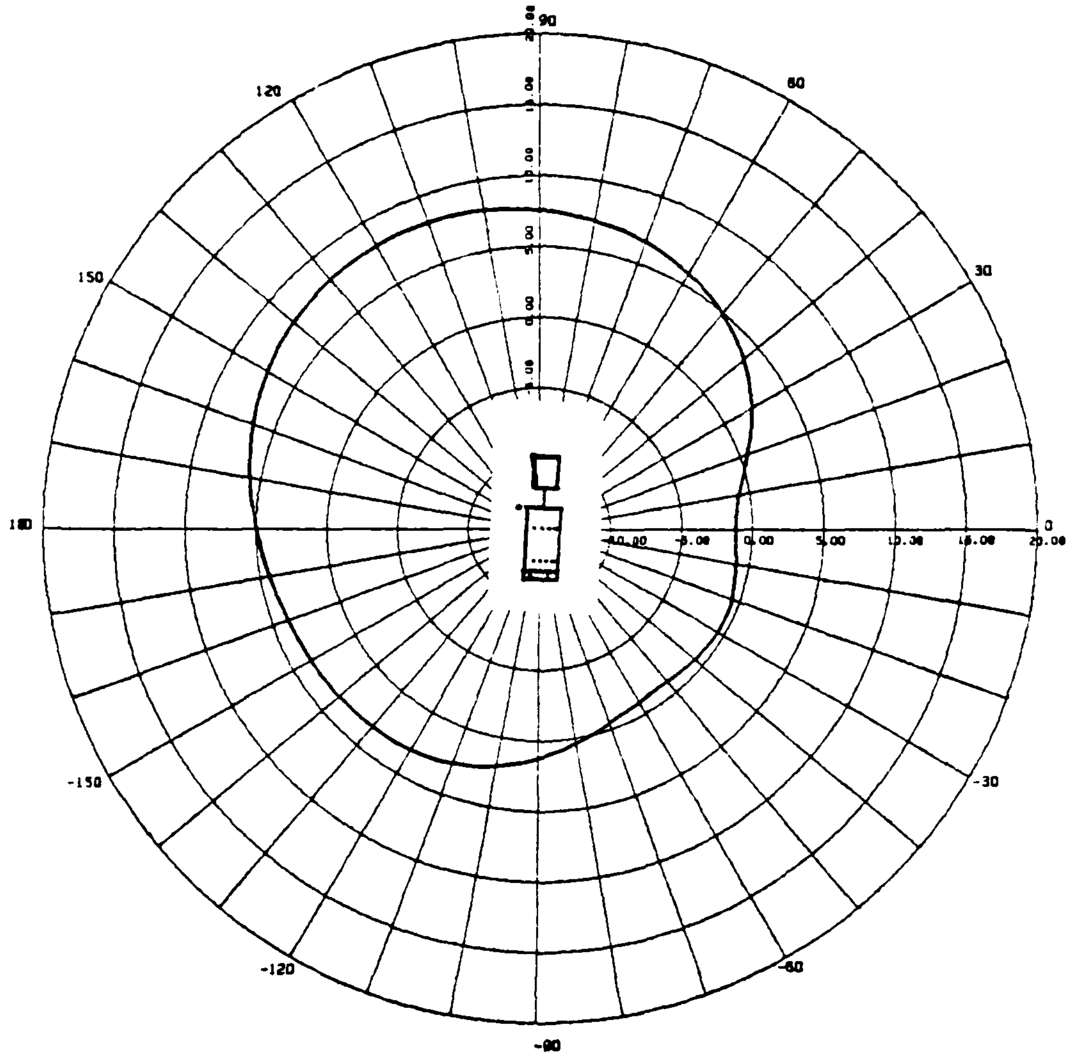
MRC-109 / THETA / PHI=120

PER GRND / JEEP & TRLR / 41 MHZ



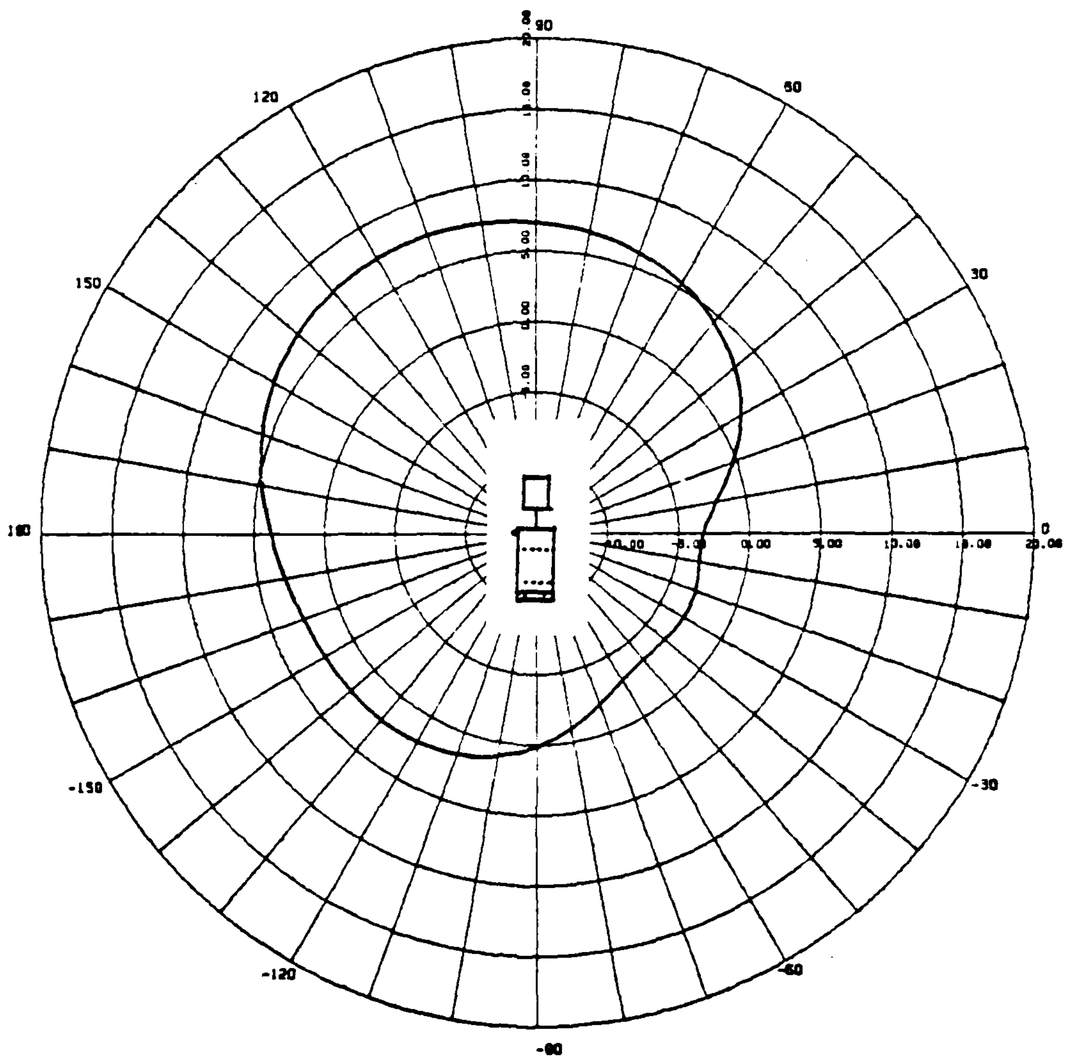
MRC-109 / PHI / THETA=90

PER GRND / JEEP & TRLR / 50 MHZ



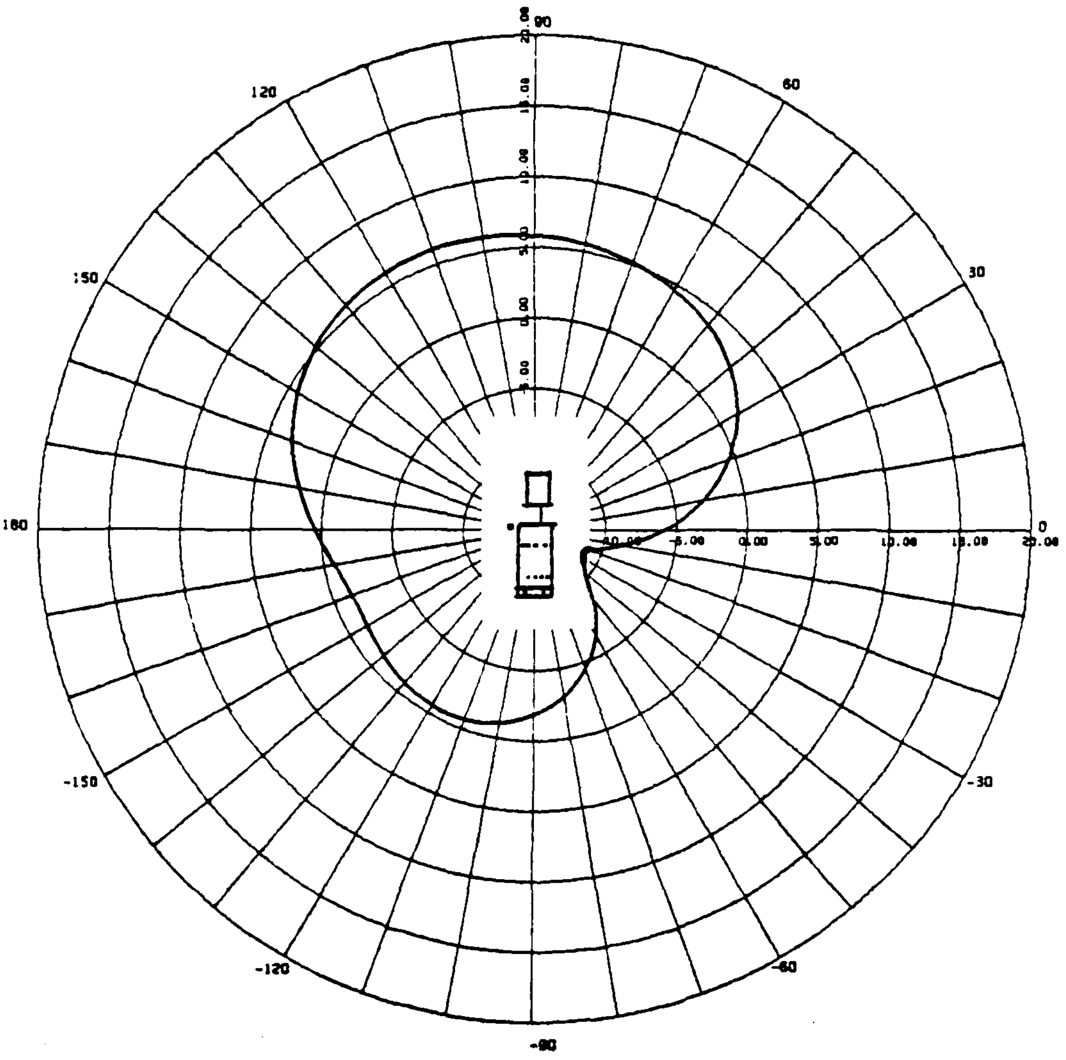
MAC-109 / PHI / THETA=80

PER GRND / JEEP & TALR / 50 MHZ



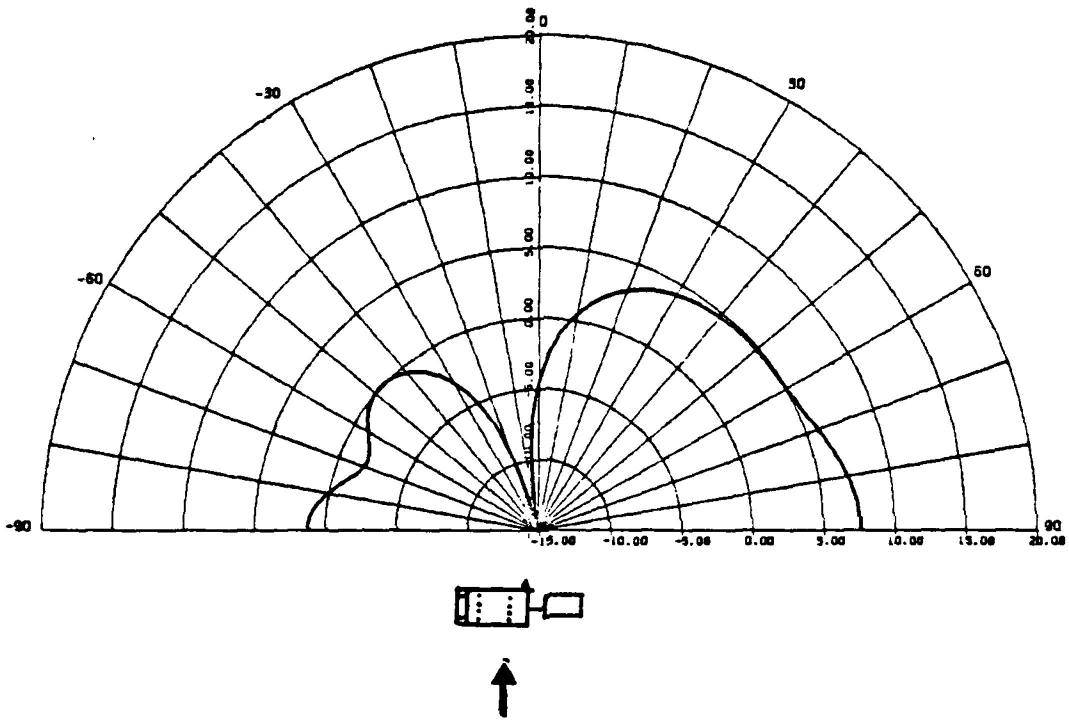
MAC-109 / PHI / THETA=70

PER GAND / JEEP & TALA / 50 MHZ



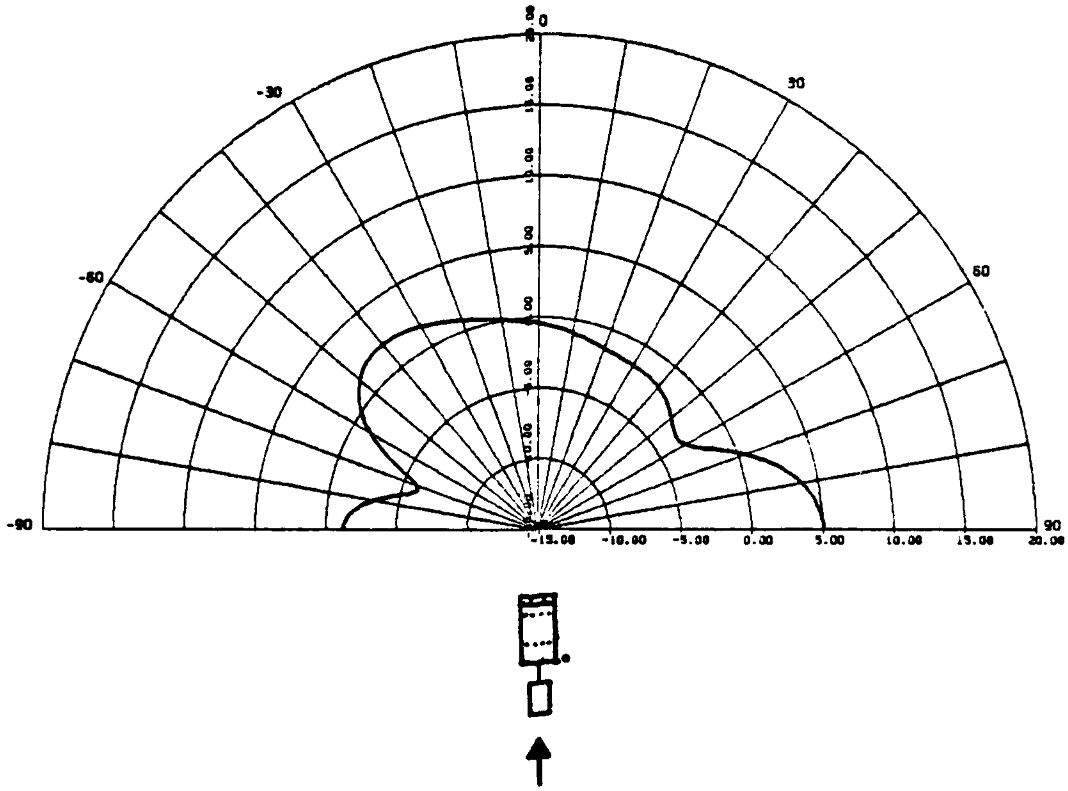
MRC-109 / THETA / PHI=90

PER GRND / JEEP & TRL9 / 50 MHZ



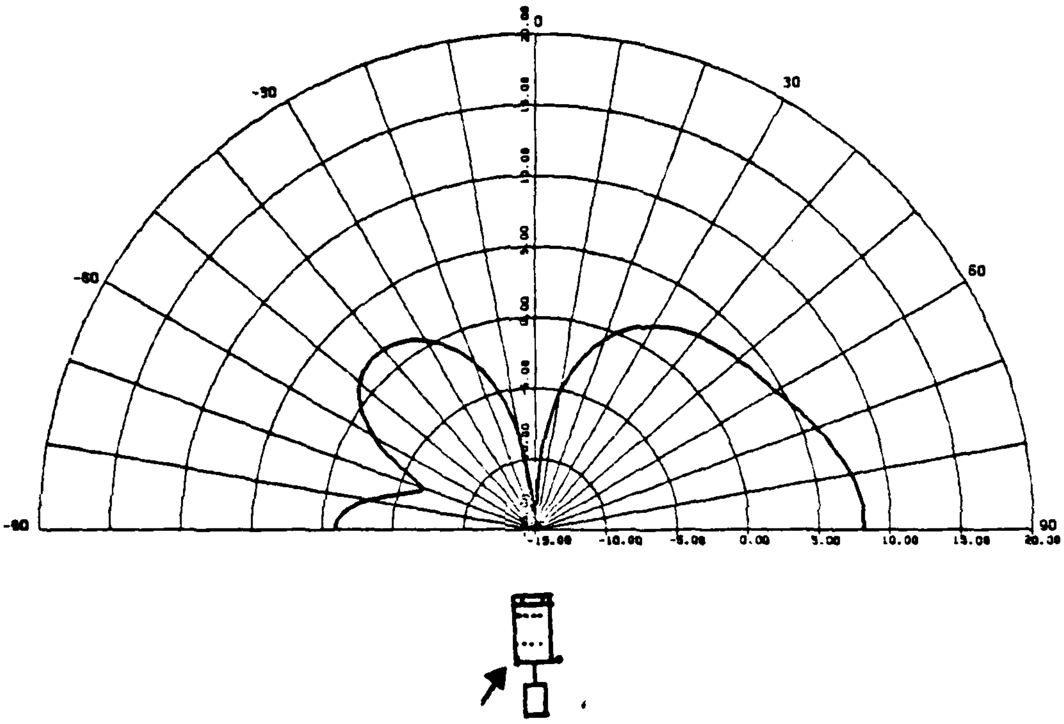
MAC-109 / THETA / PHI=180

PER GRND / JEEP & TRLR / 50 MHZ



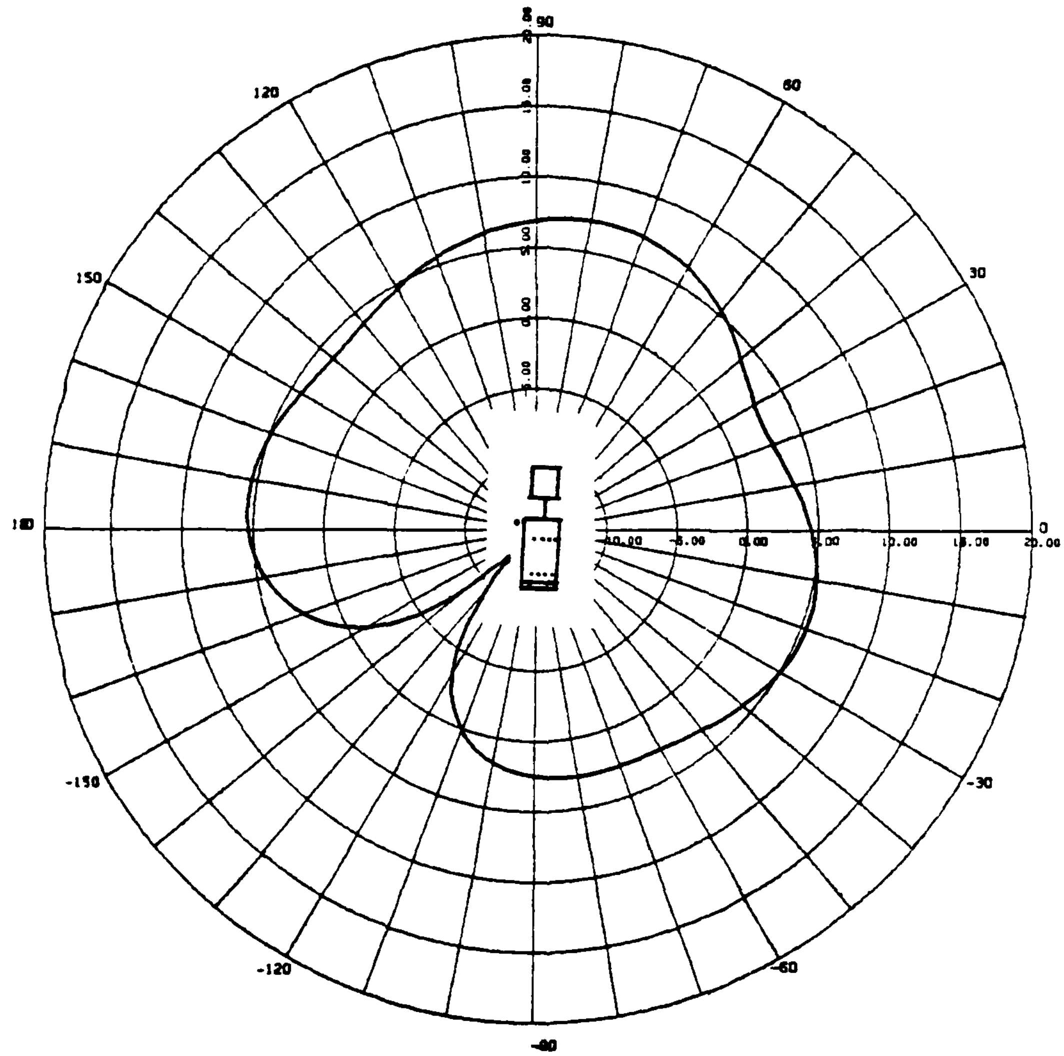
MRC-109 / THETA / PHI=120

PER GRND / JEEP & TRLR / 50 MHZ



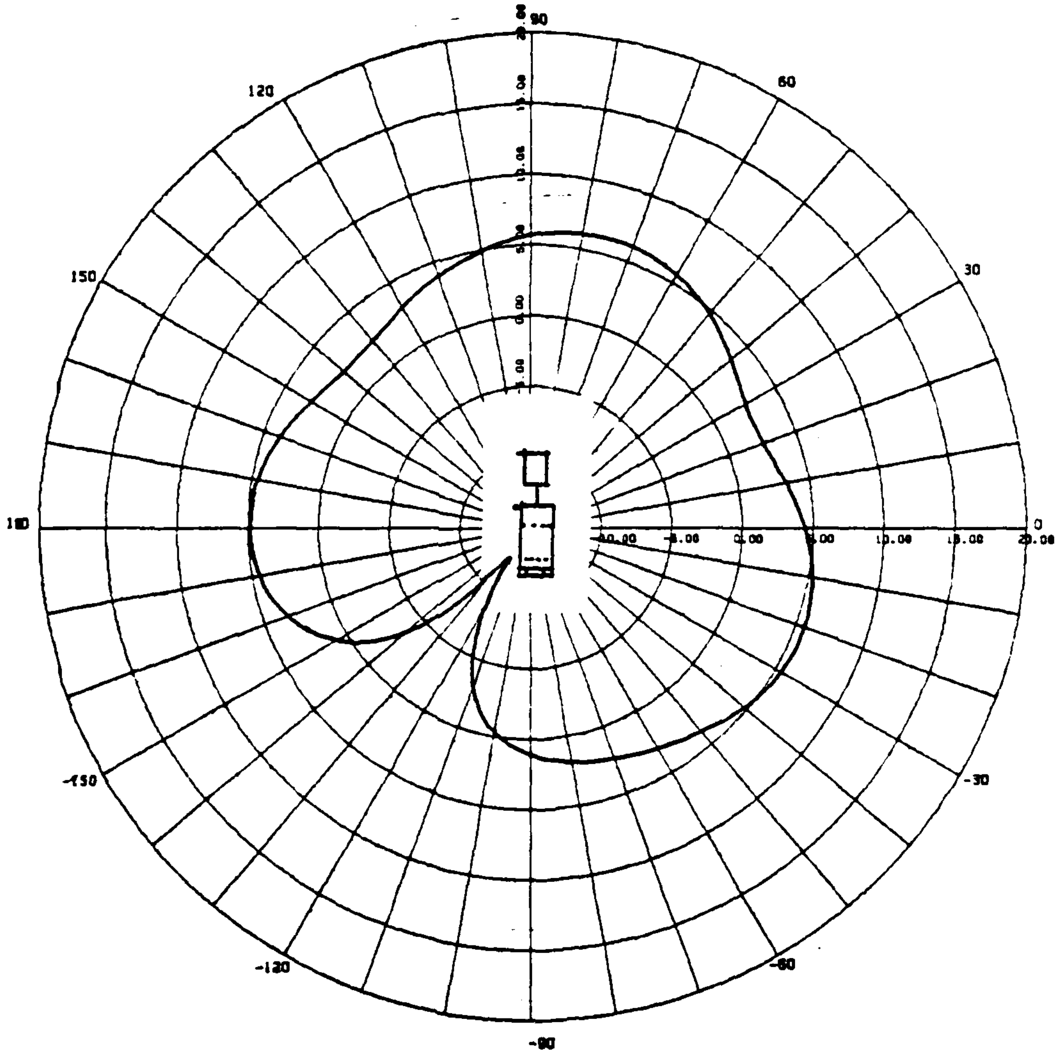
MAC-109 / PHI / THETA=90

PER GRND / JEEP & TRLR / 75 MHZ



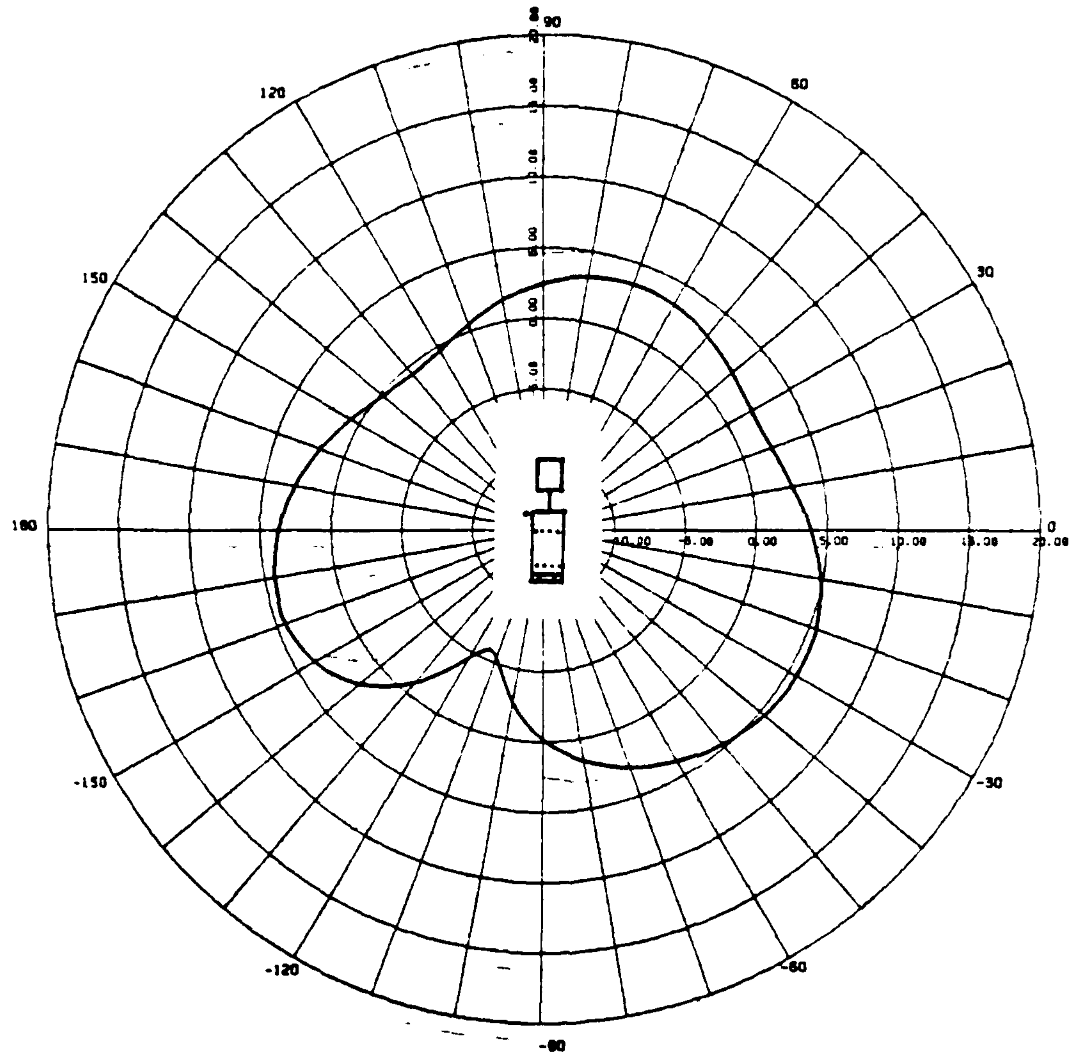
MAC-103 / PHI / THETA=80

PER GRND / JEEP & TRLR / 75 MHZ



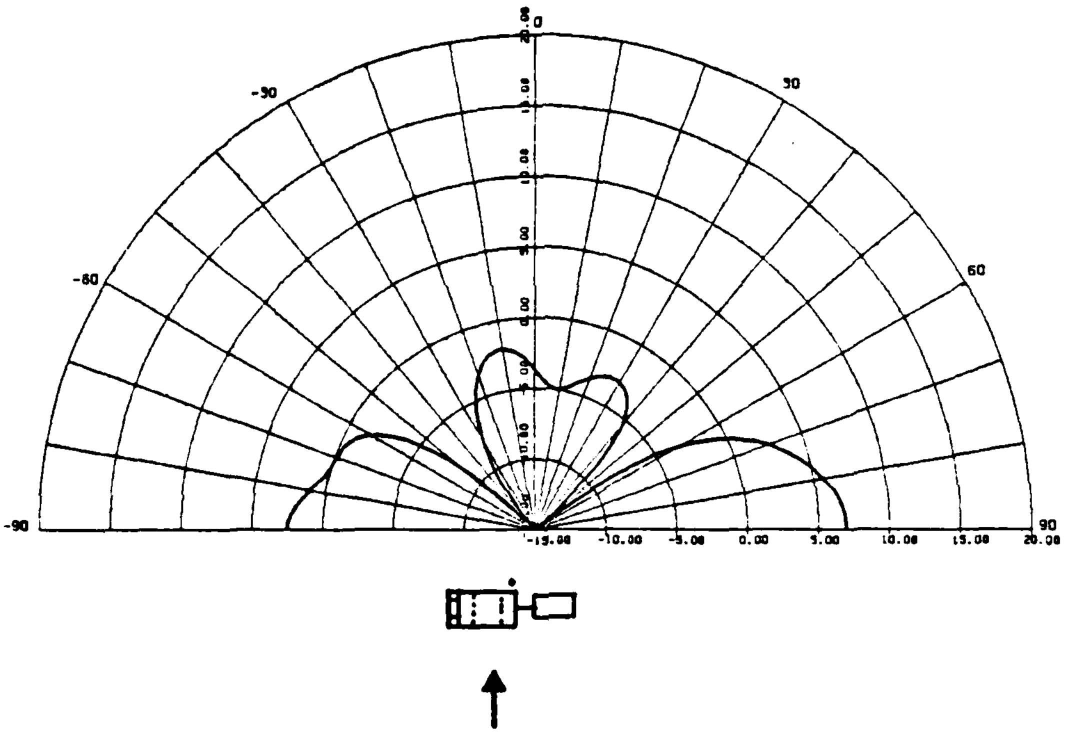
MAC-IOS / PHI / THETA=70

PER GRND / JEEP & TRLR / 75 MHZ



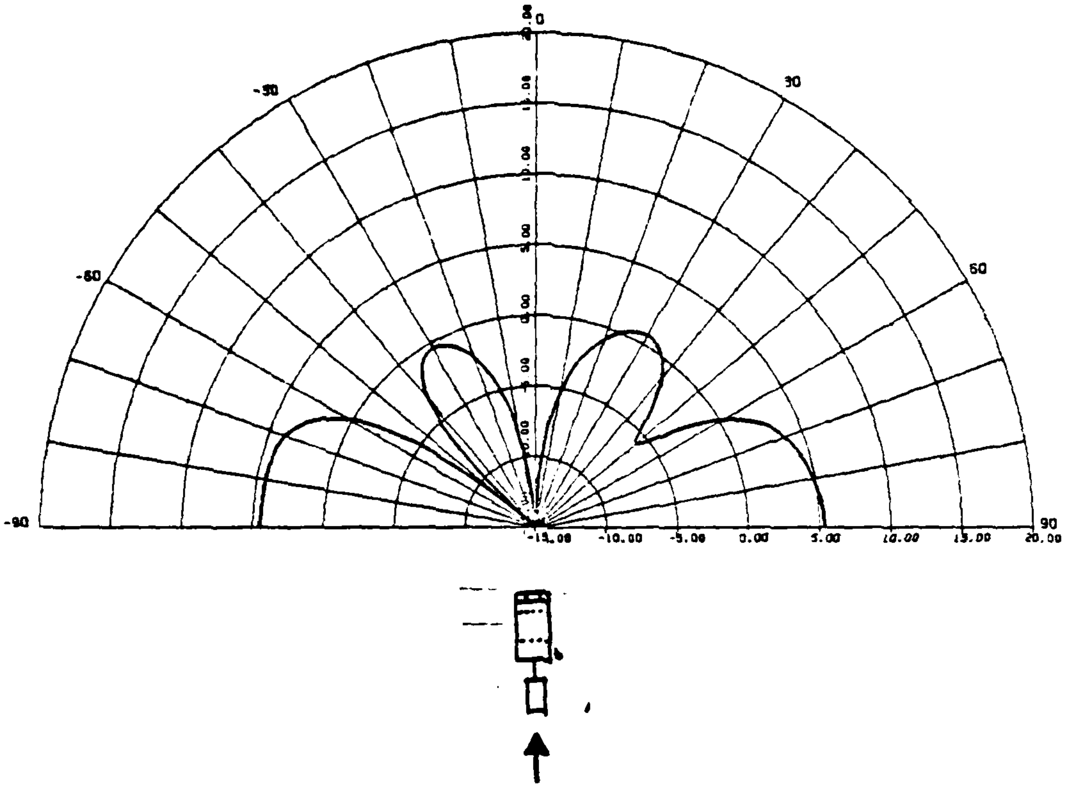
MRC-109 / THETA / PHI=90

PER GRND / JEEP & TRLR / 75 MHZ



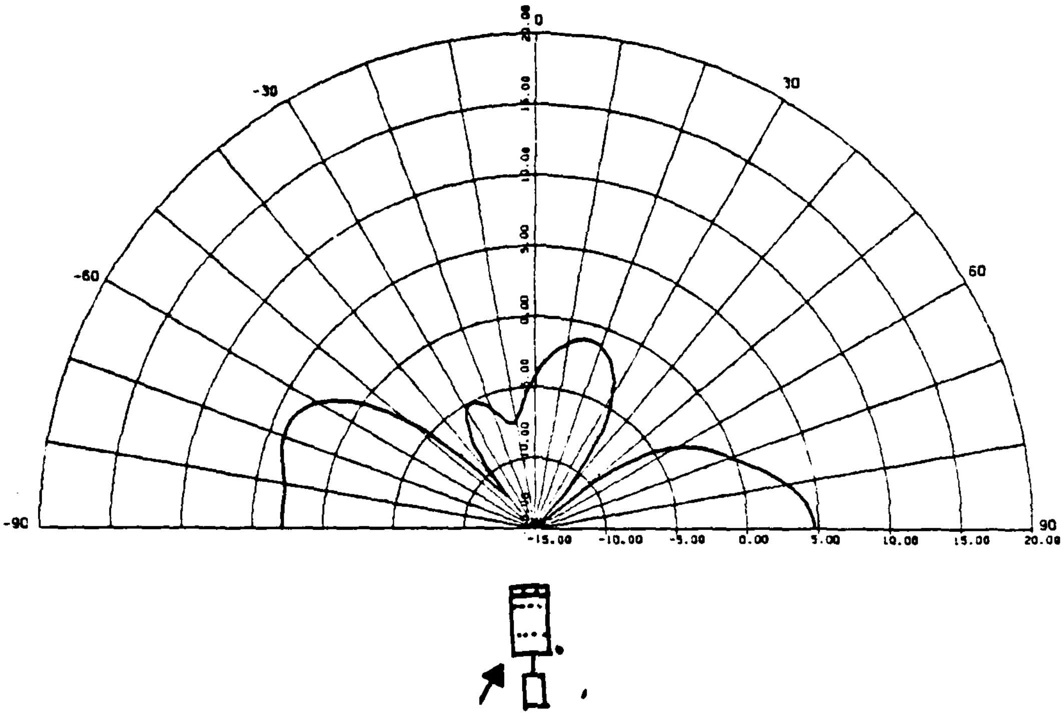
MAC-109 / THETA / PHI=180

PER GAND / JEEP & TALA / 75 MHZ



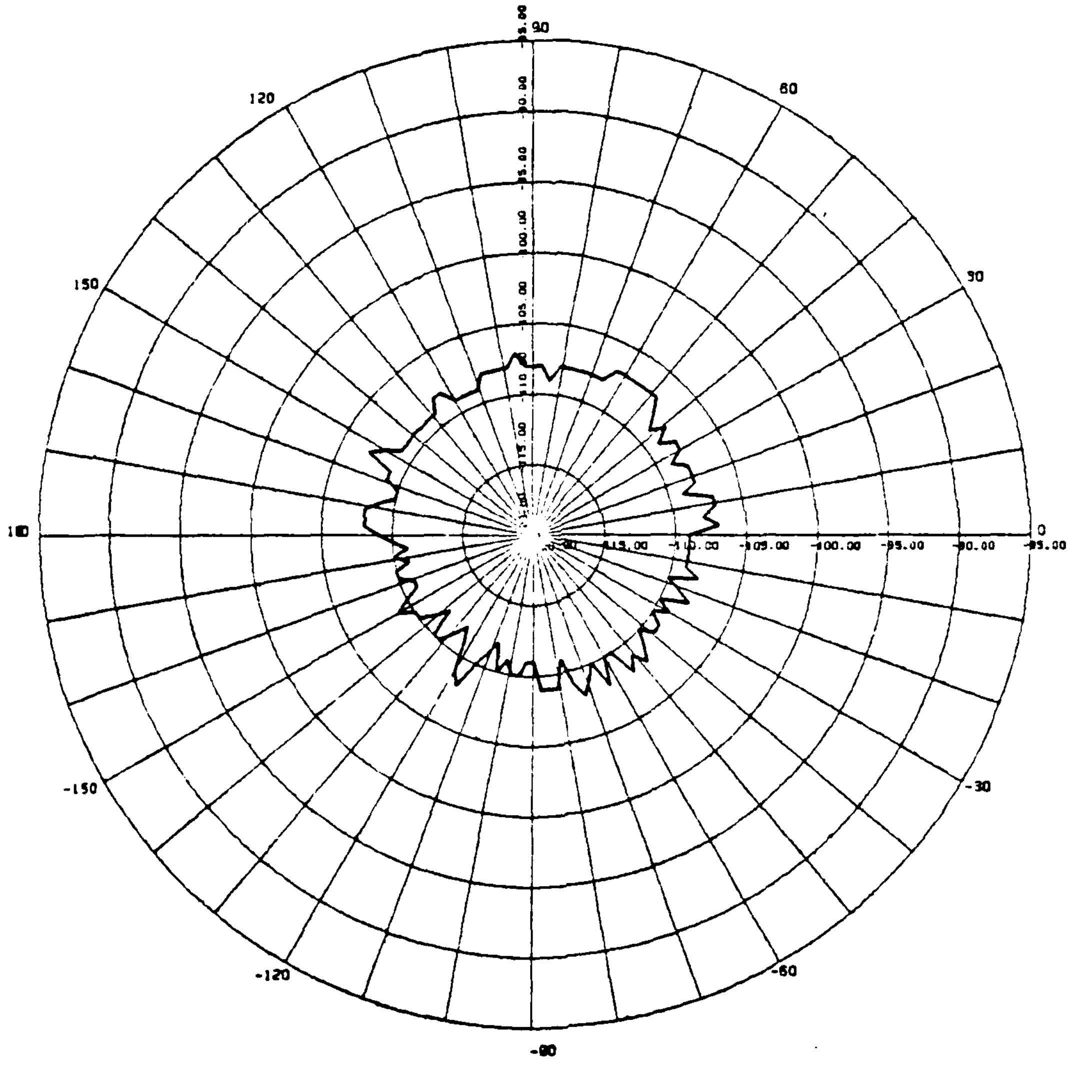
MRC-109 / THETA / PHI=120

PER GRND / JEEP & TRLR / 75 MHZ



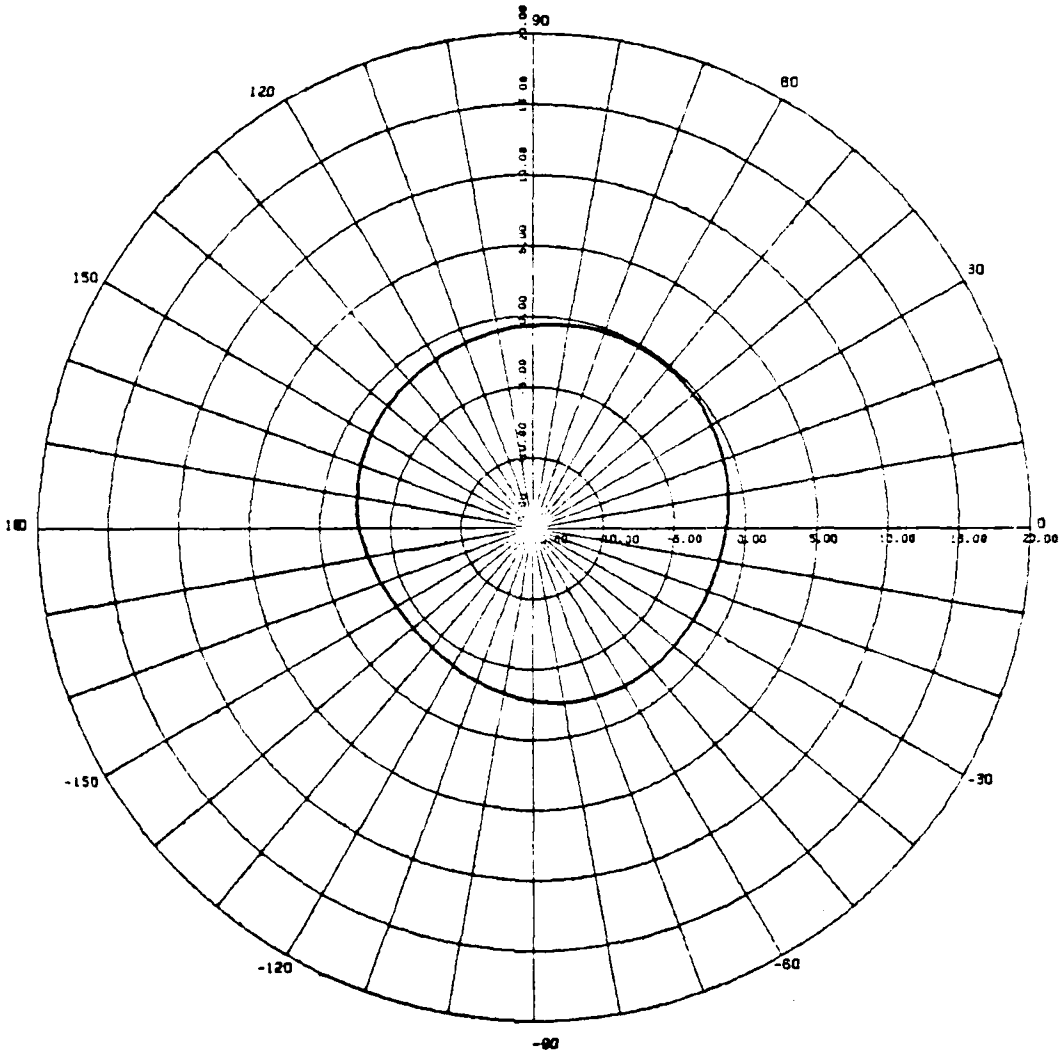
MRC-109 / PHI / THETA=90

WET GROUND / BASIC / 30 MHZ



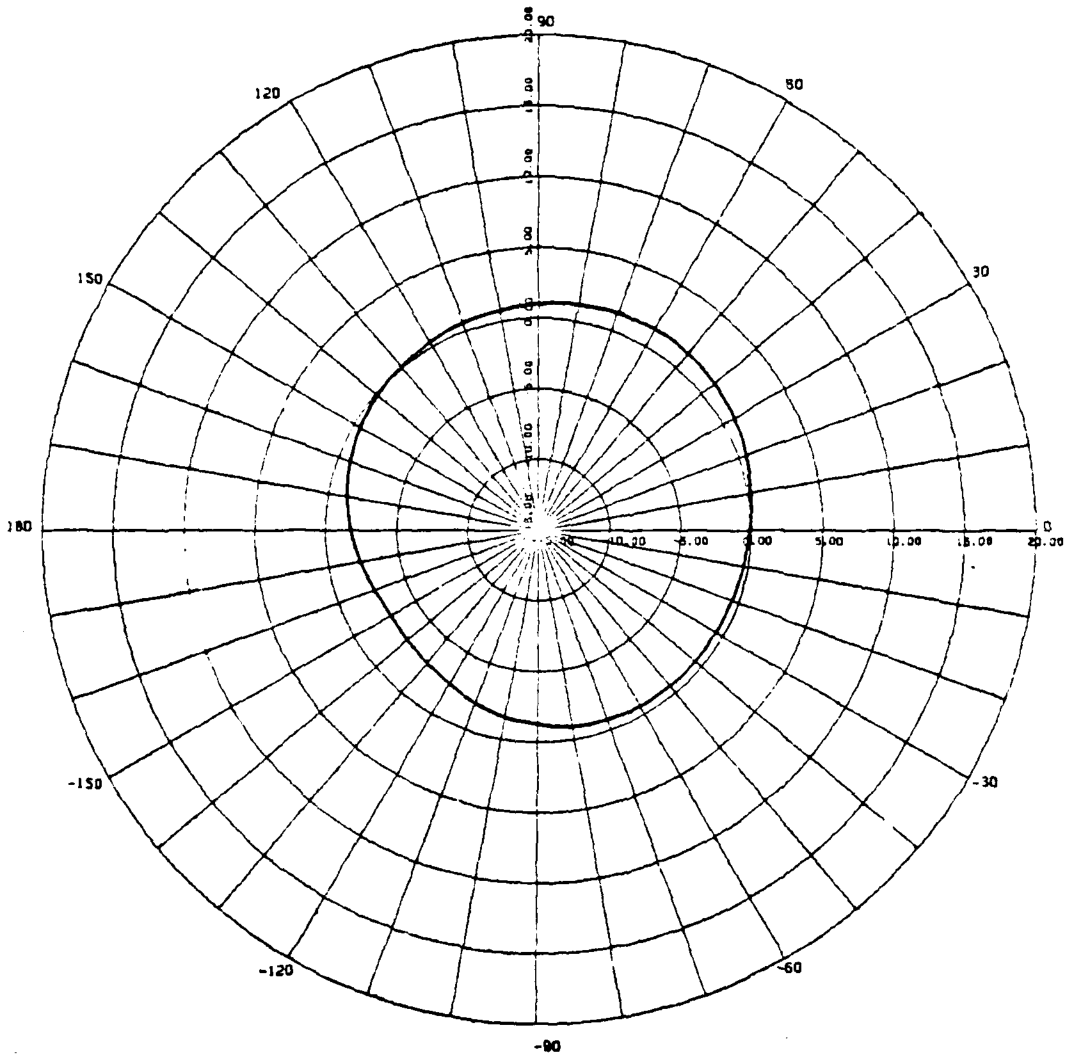
MRC-109 / PHI / THETA= 90

WET GROUND / BASIC / 30 MHZ



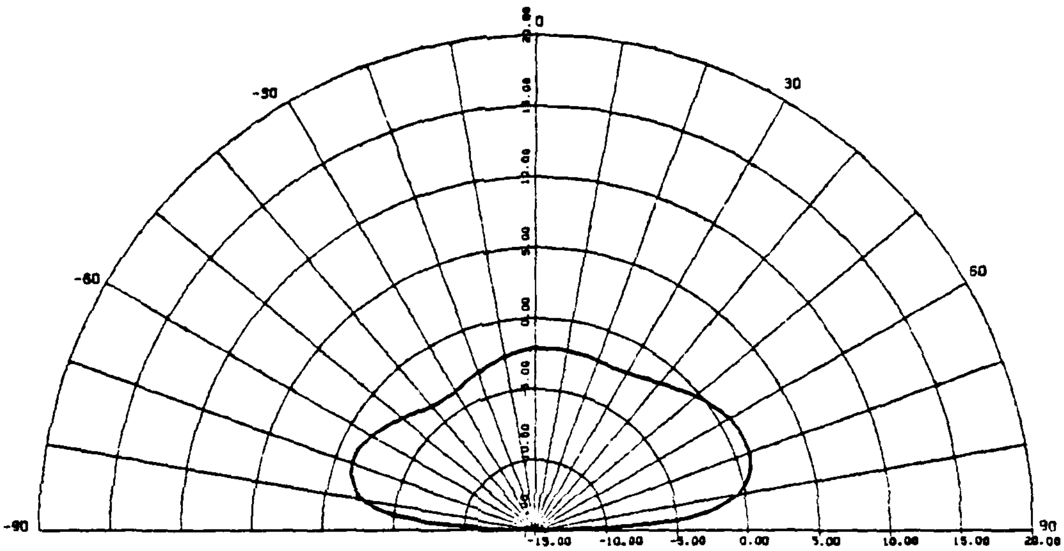
MRC-109 / PHI / THETA= 70

WET GROUND / BASIC / 30 MHZ



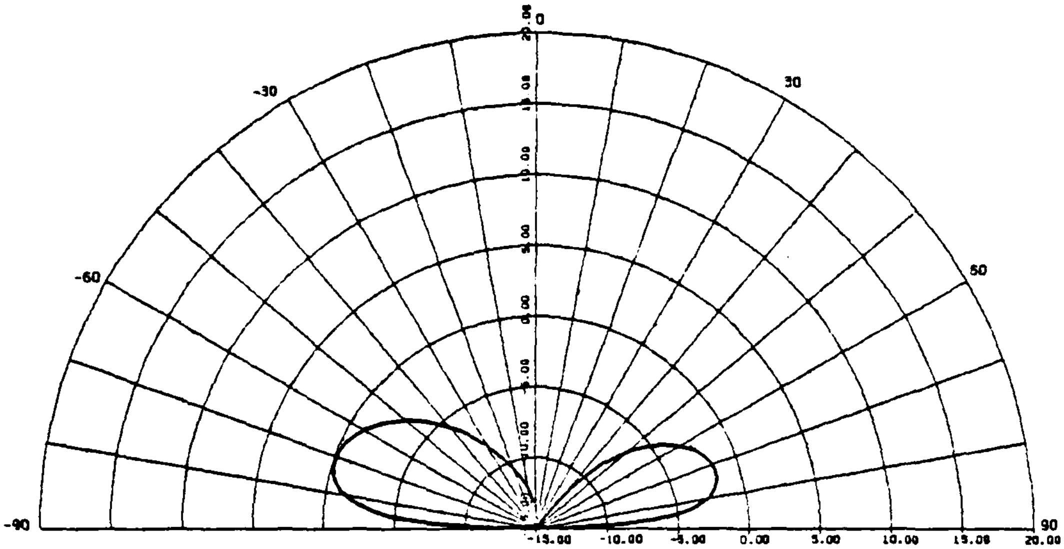
MRC-109 / THETA / PHI = 90

WET GROUND / BASIC / 30 MHZ



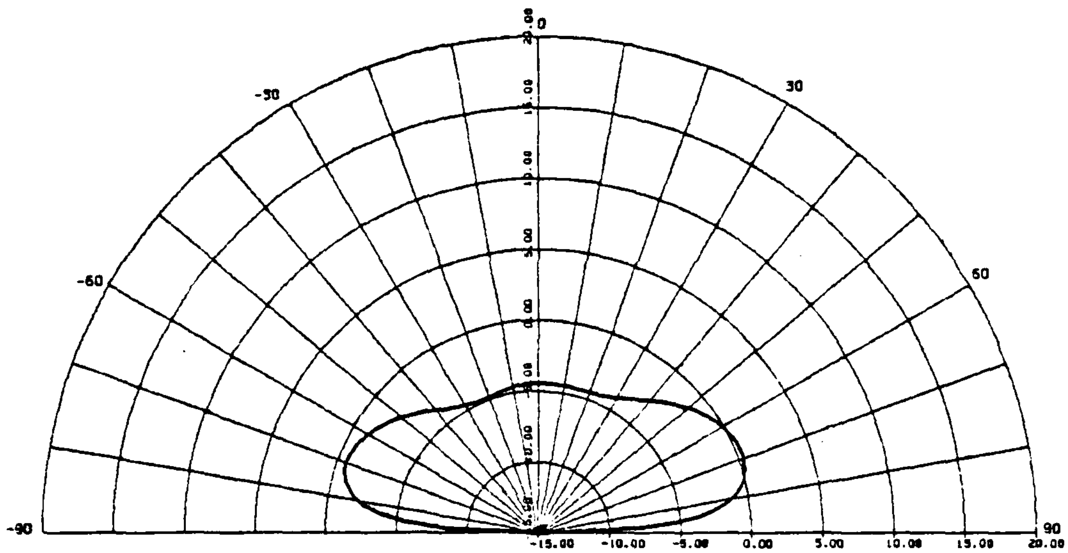
MRC-109 / THETA / PHI = 180

WET GROUND / BASIC / 30 MHZ



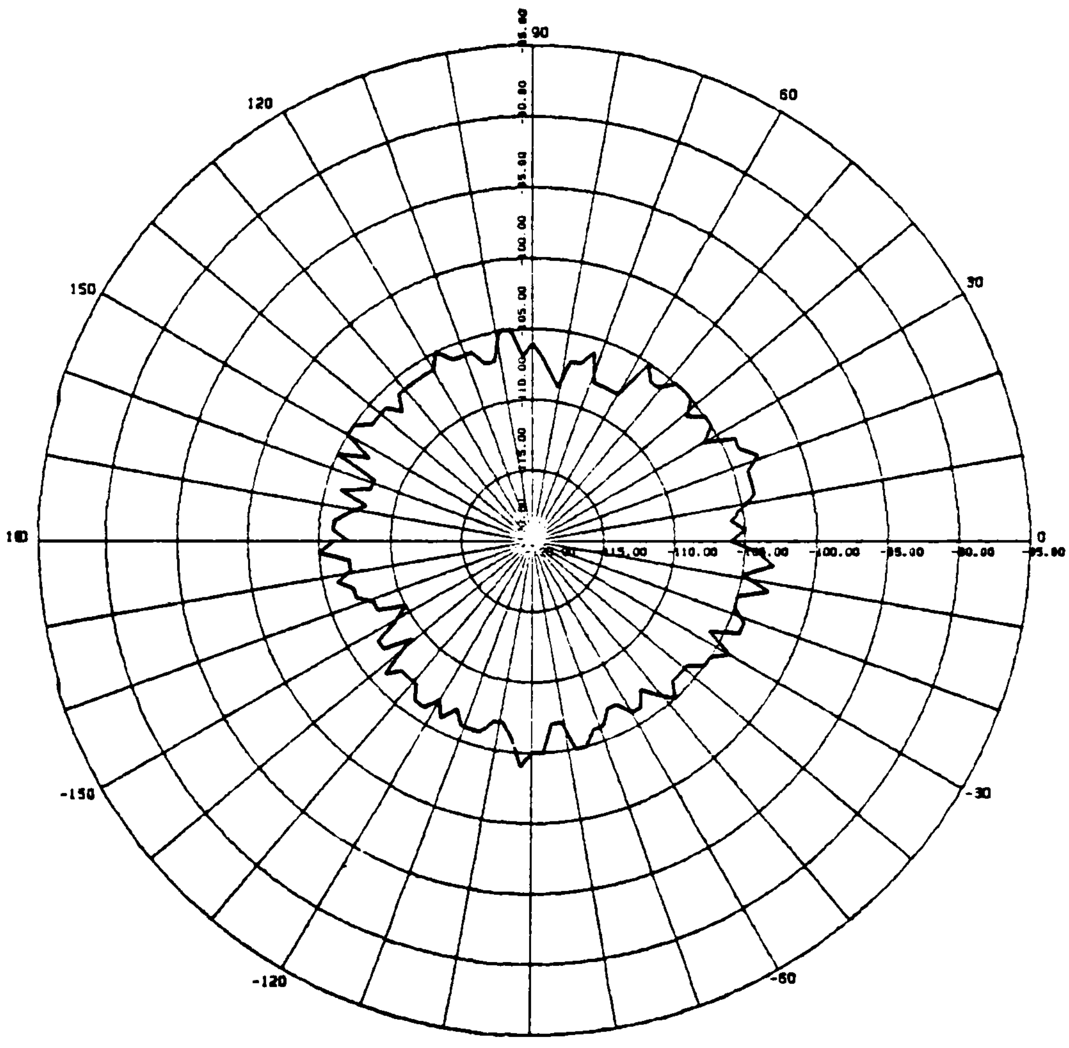
MAC-109 / THETA / PHI = 120

WET GROUND / BASIC / 30 MHZ



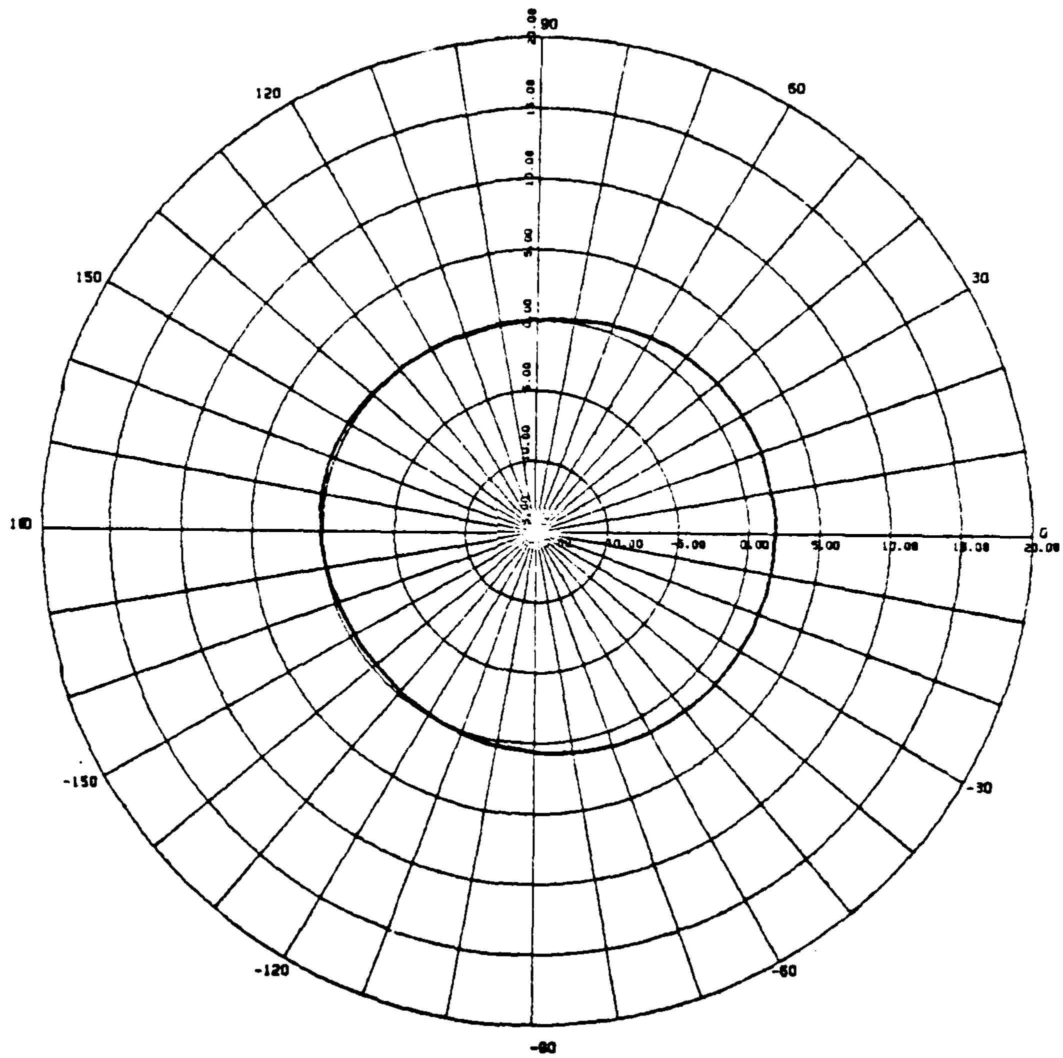
MAC-109 / PHI / THETA=90

WET GROUND / BASIC / 41 MHZ



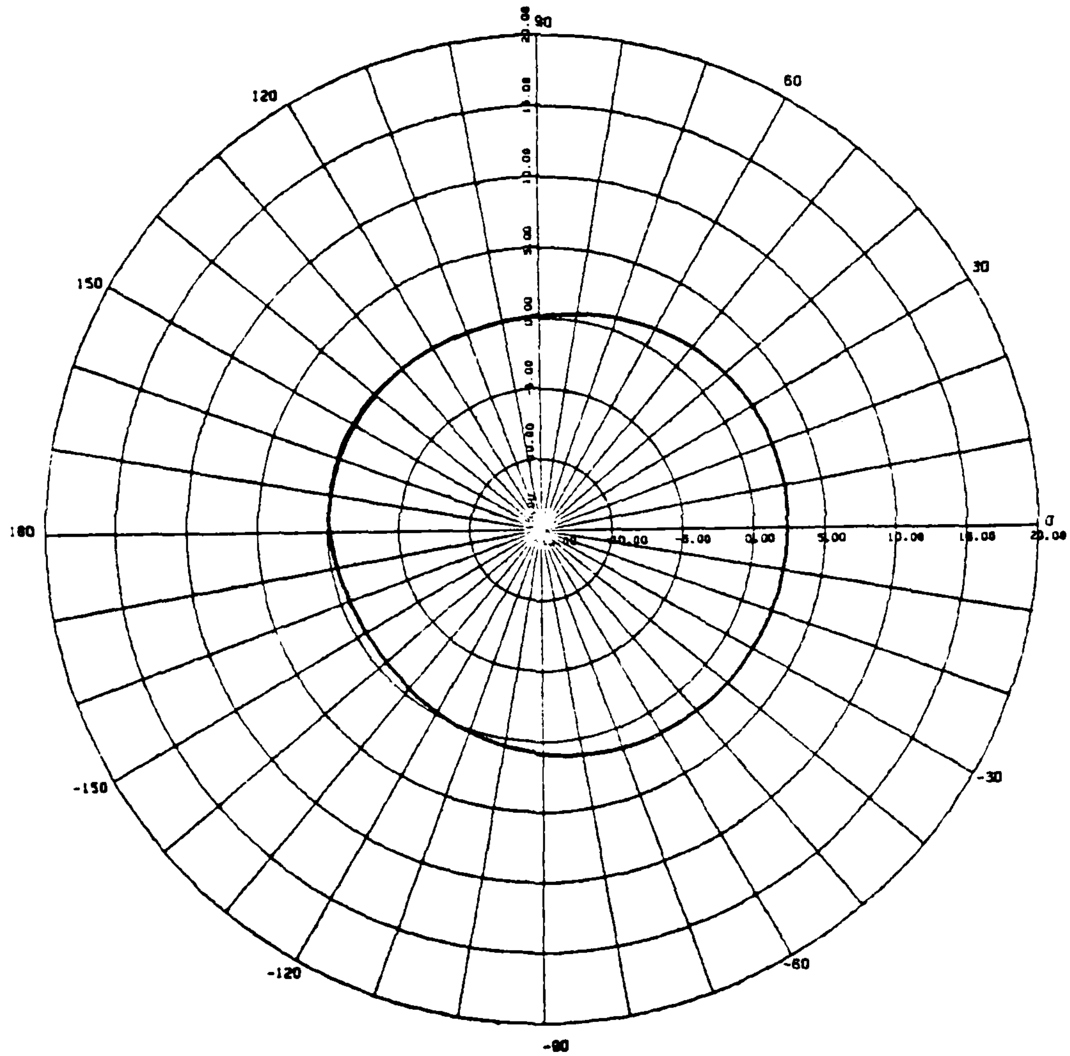
MAC-109 / PHI / THETA= 80

WET GROUND / BASIC / 41 MHZ



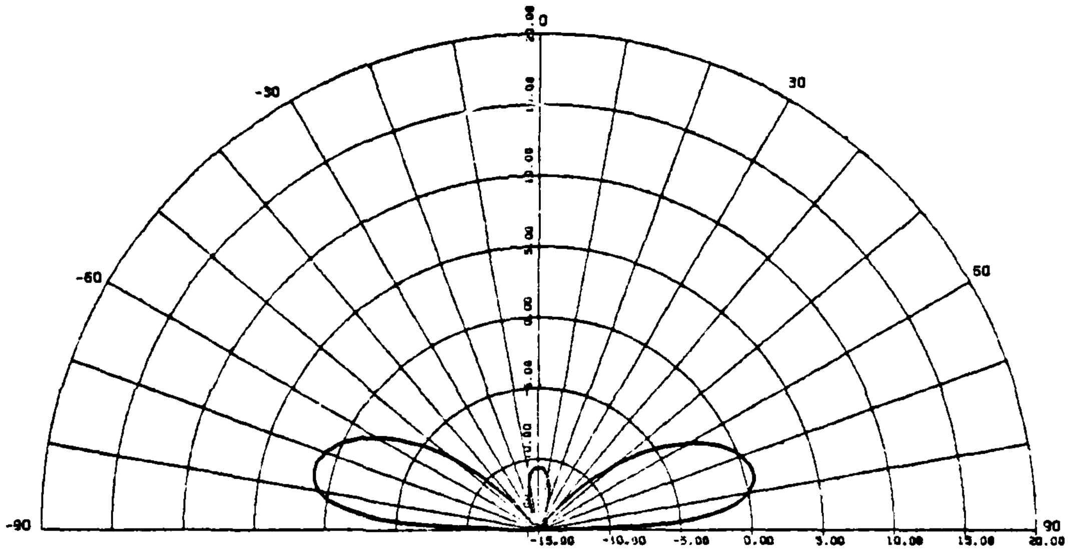
MAC-109 / PHI / THETA= 70

WET GROUND / BASIC / 41 MHZ



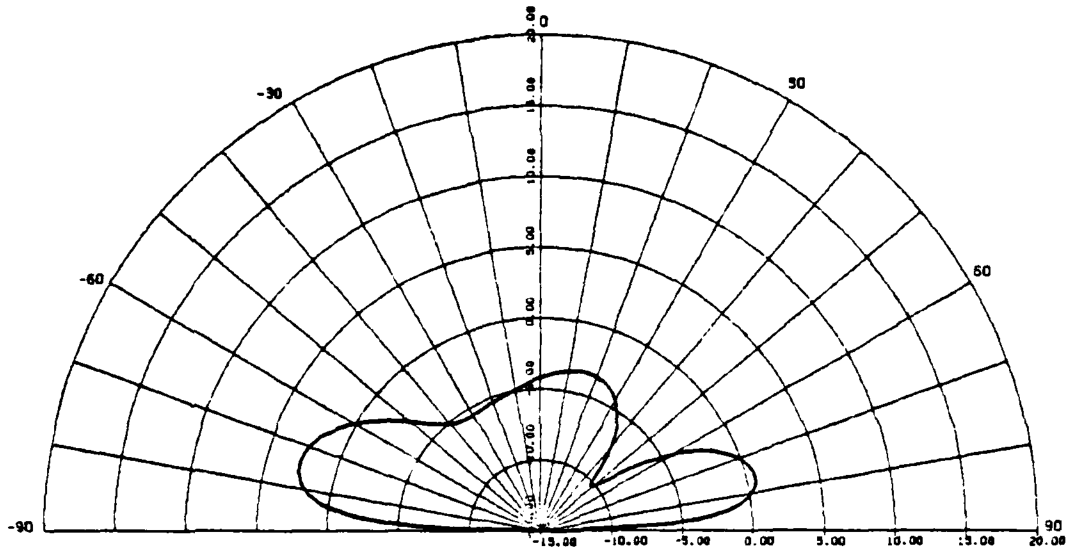
MRC-109 / THETA / PHI = 90

WET GROUND / BASIC / 41 MHZ



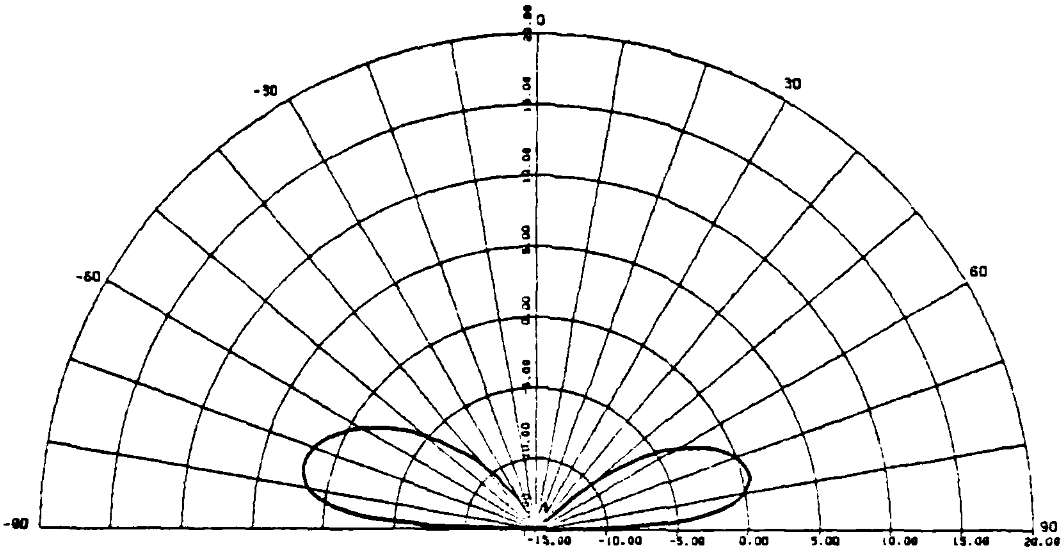
MAC-109 / THETA / PHI = 180

WET GROUND / BASIC / 41 MHZ



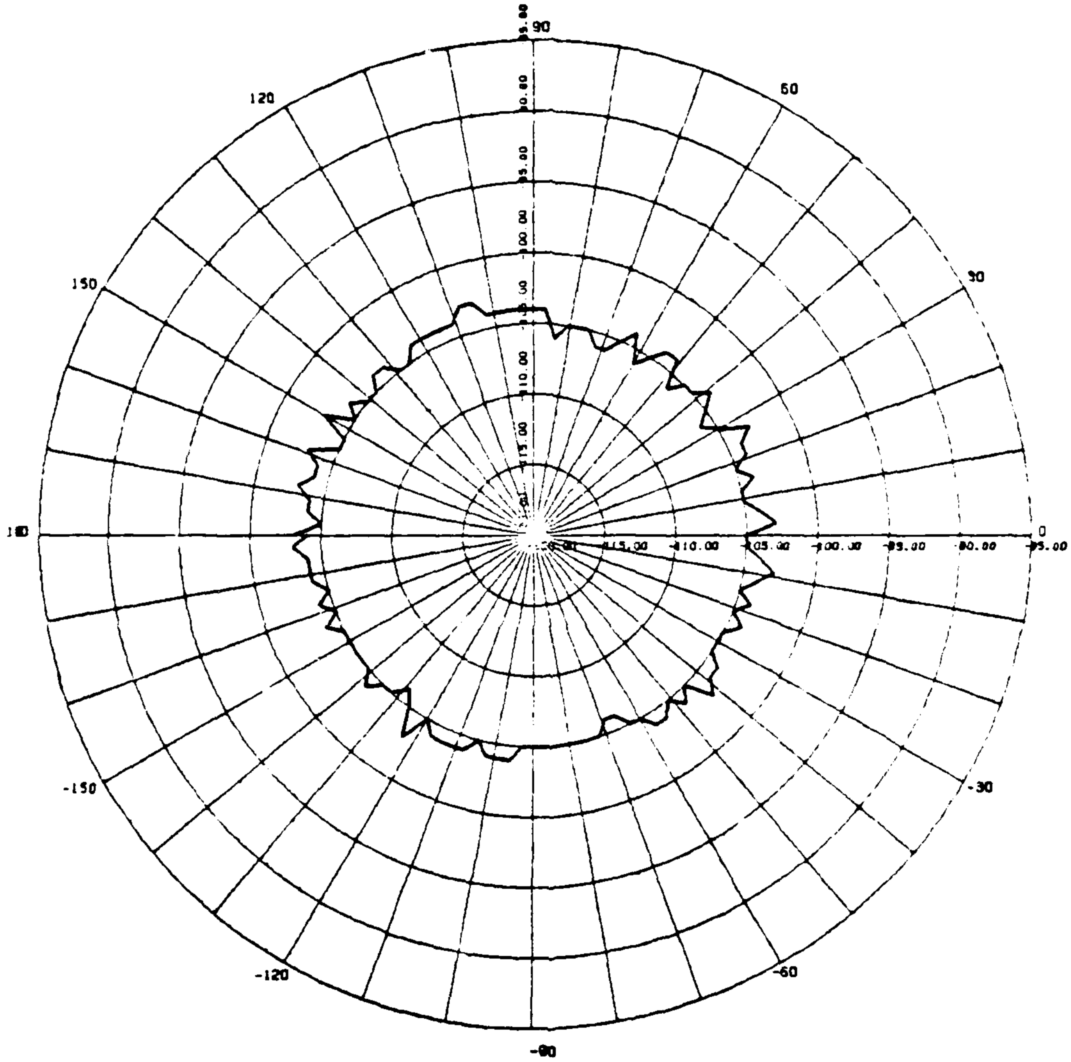
MRC-109 / THETA / PHI = 120

WET GROUND / BASIC / 41 MHZ



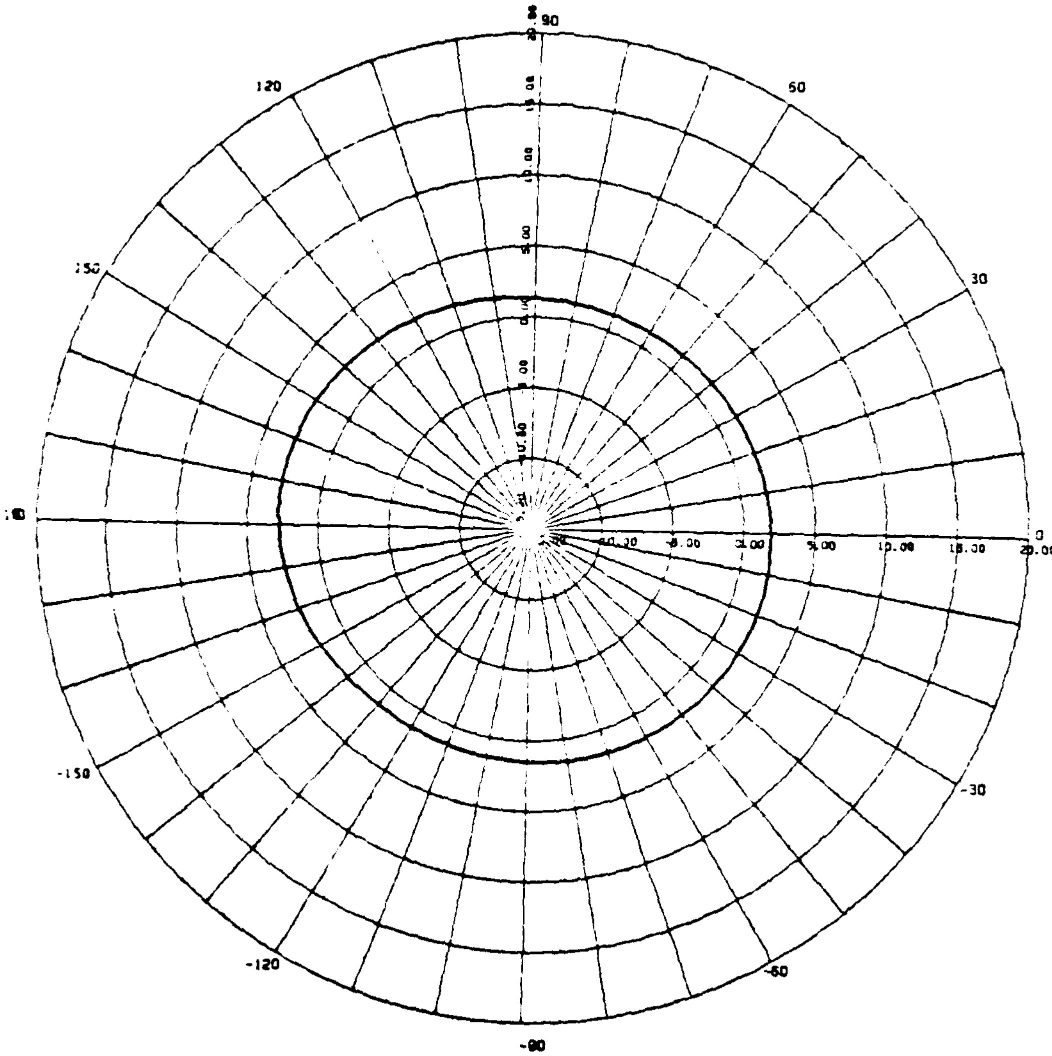
MAC-109 / PHI / THETA=90

WET GROUND / BASIC / 50 MHZ



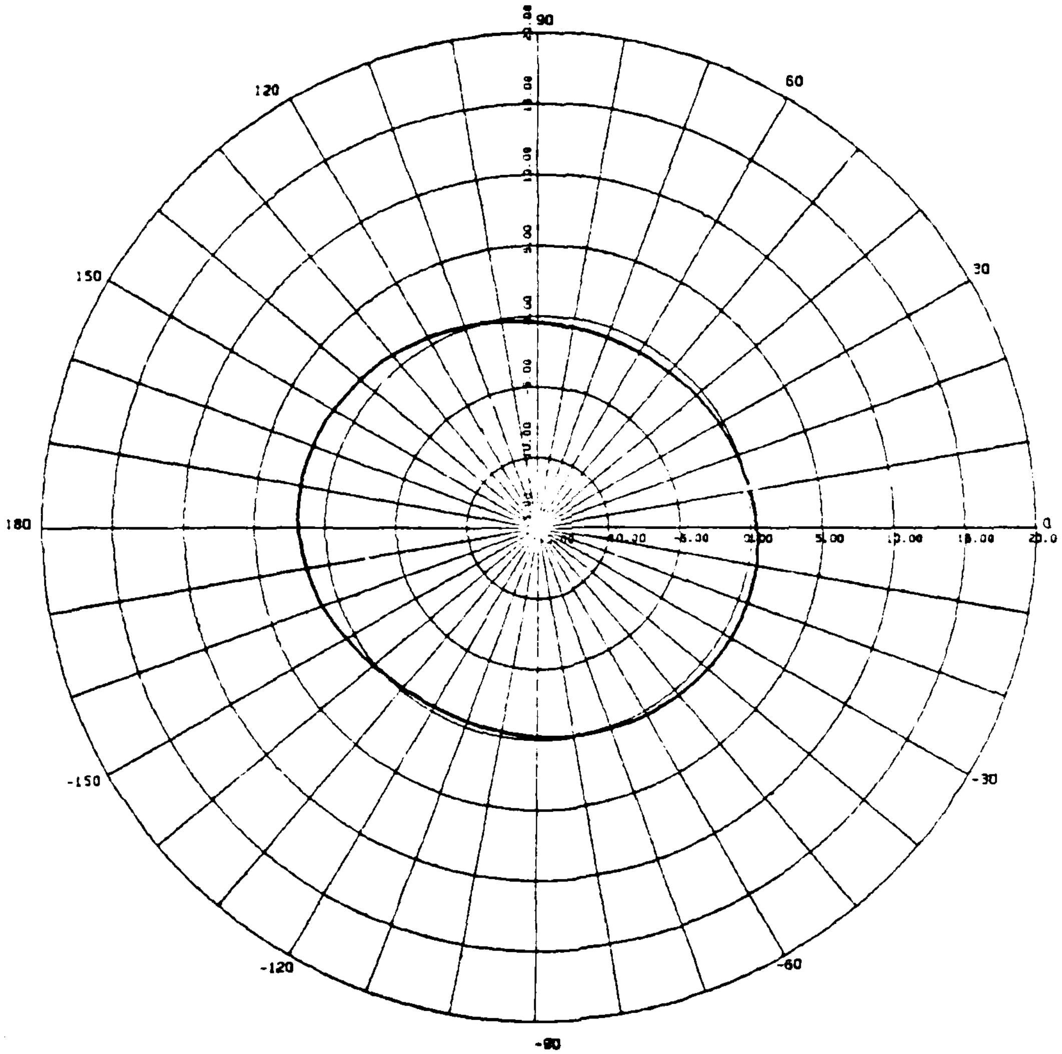
MAC-109 / PHI / THETA= 90

WET GROUND / BASIC / 50 MHZ



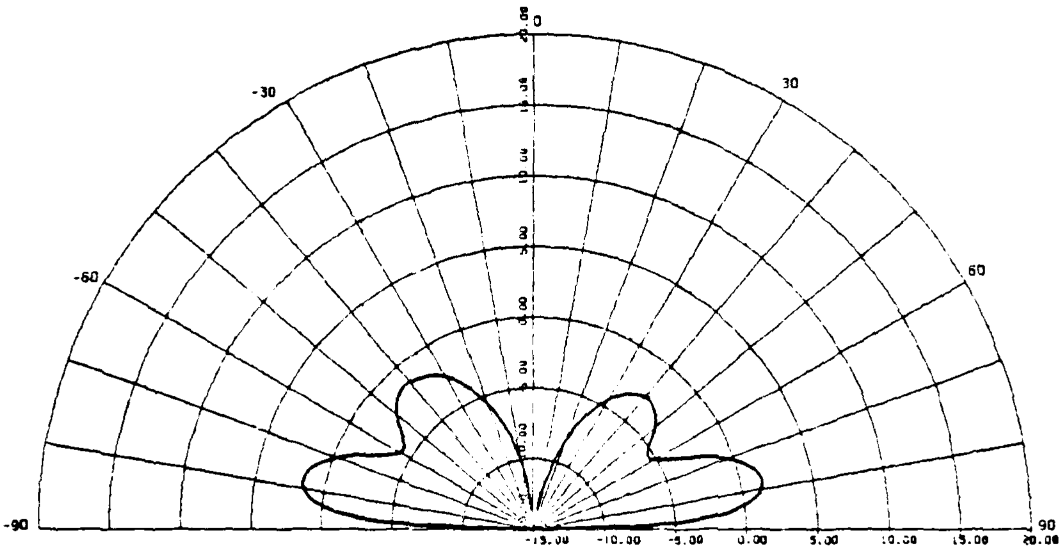
MAC-109 / PHI / THETA= 70

WET GROUND / BASIC / 50 MHZ



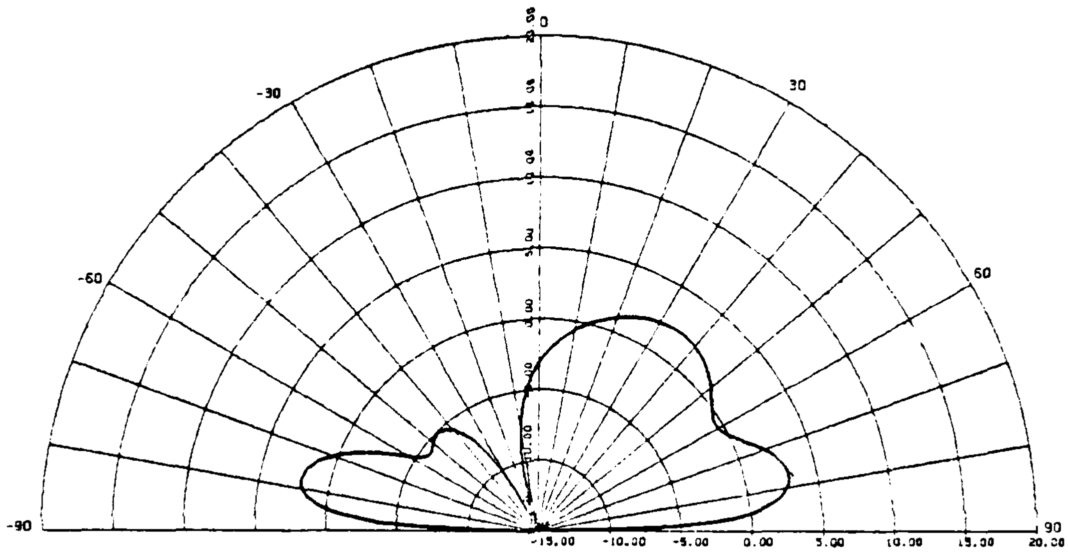
MRC-108 / THETA / PHI = 30

WET GROUND / BASIC / 50 MHZ



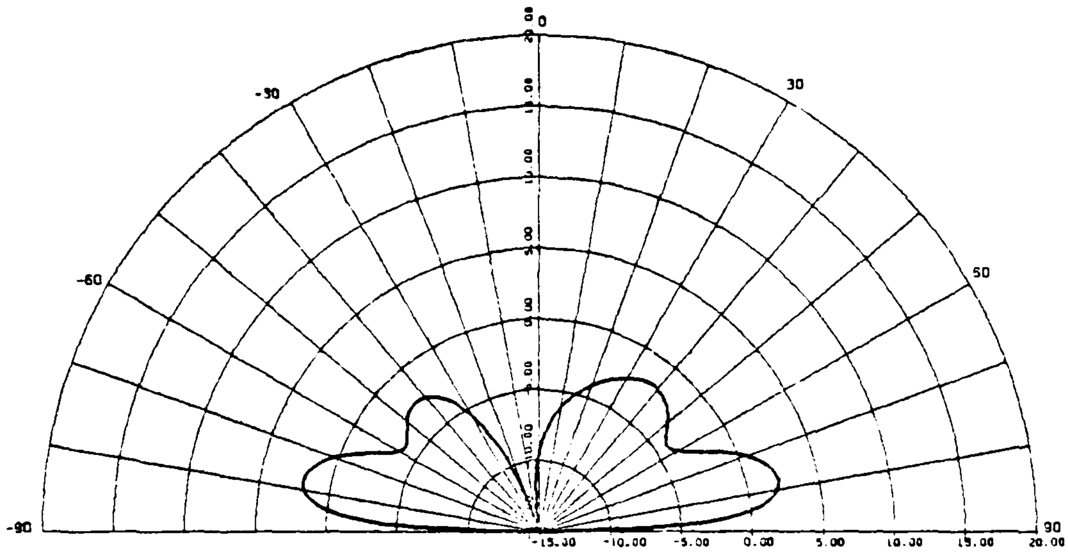
MRC-105 / THETA / PHI = 180

WET GROUND / BASIC / 50 MHZ



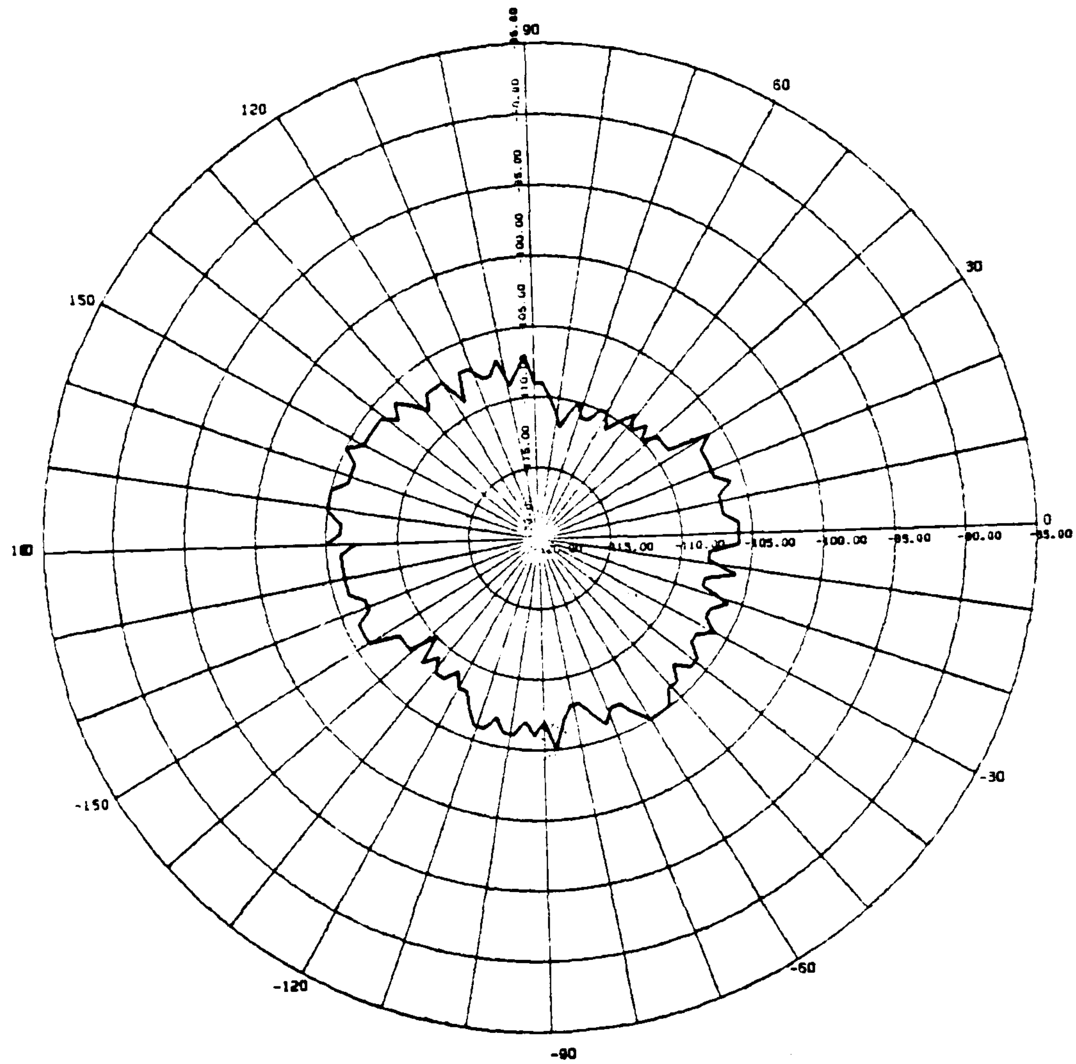
MAC-109 / THETA / PHI = 120

WET GROUND / BASIC / 50 MHZ



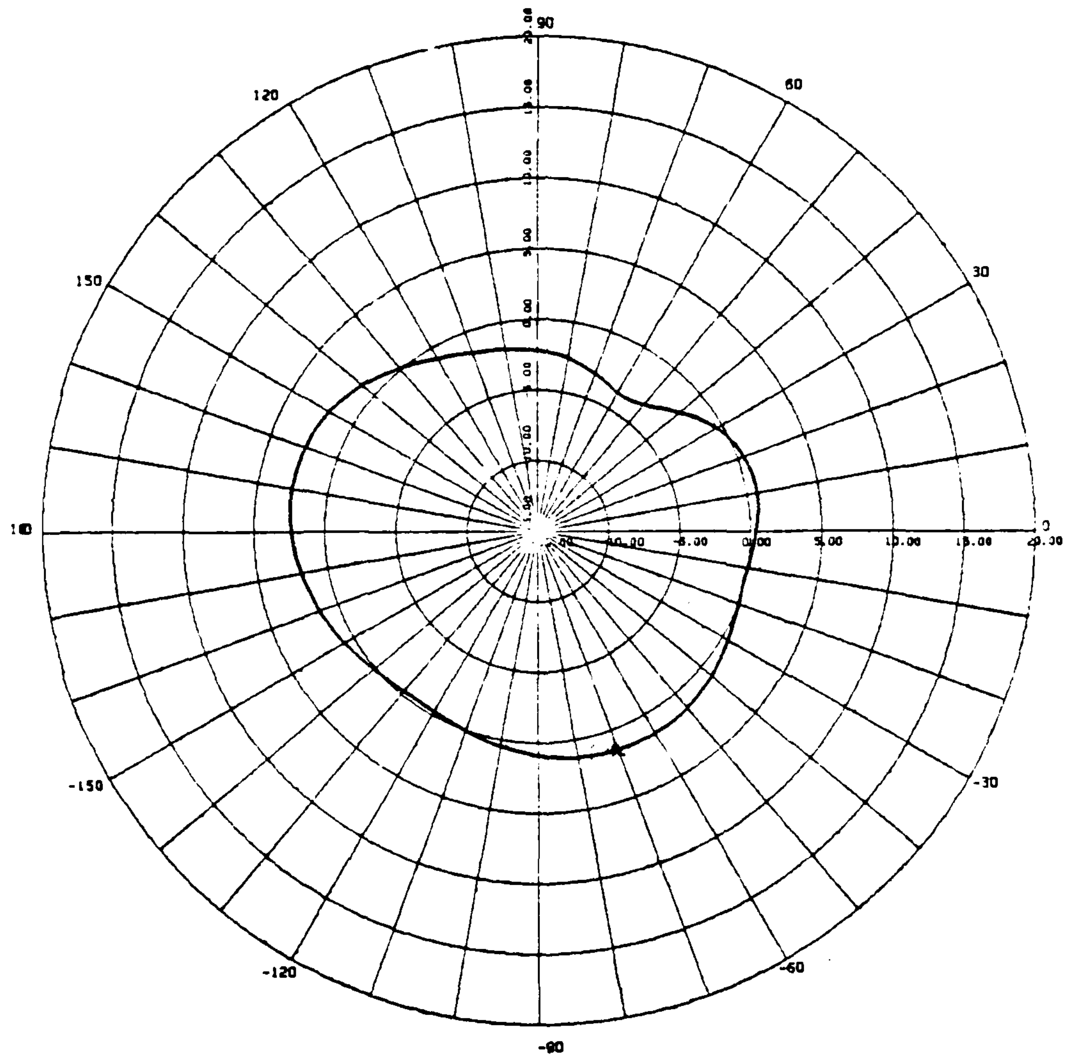
MAC-109 / PHI / THETA-90

WET GROUND / BASIC / 75 MHZ



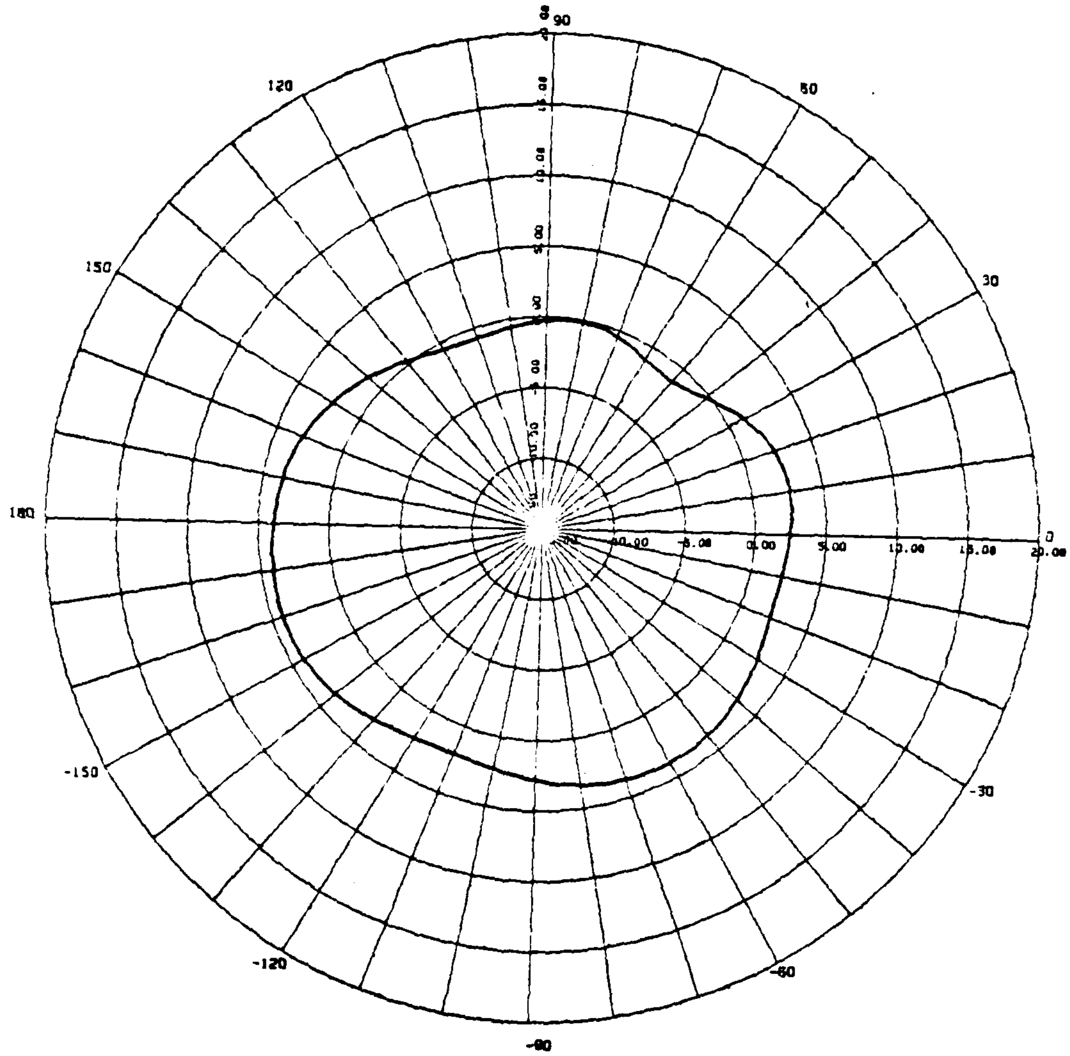
MAC-109 / PHI / THETA= 80

WET GROUND / BASIC / 75 MHZ



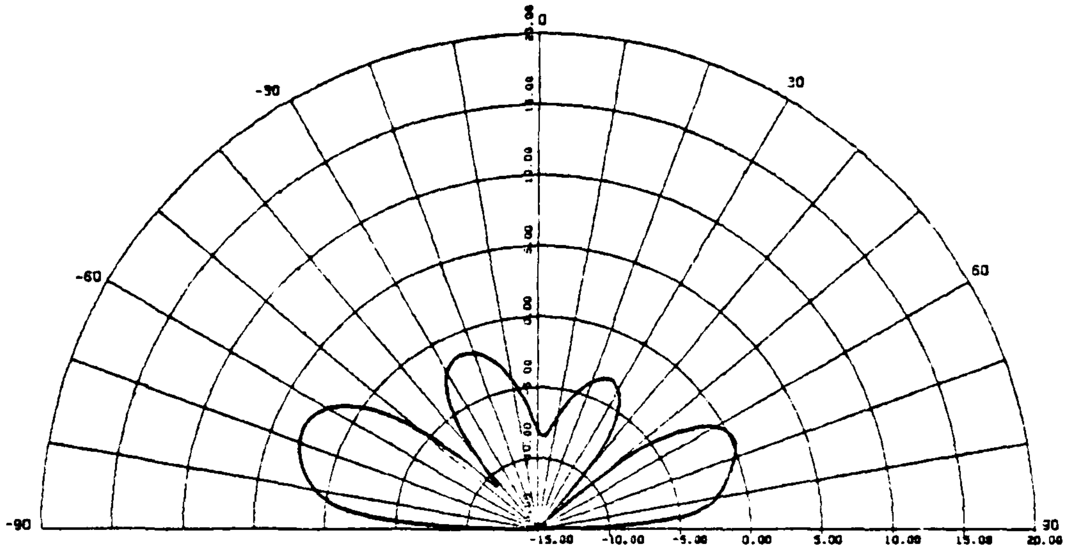
MAC-109 / PHI / THETA= 70

WET GROUND / BASIC / 75 MHZ



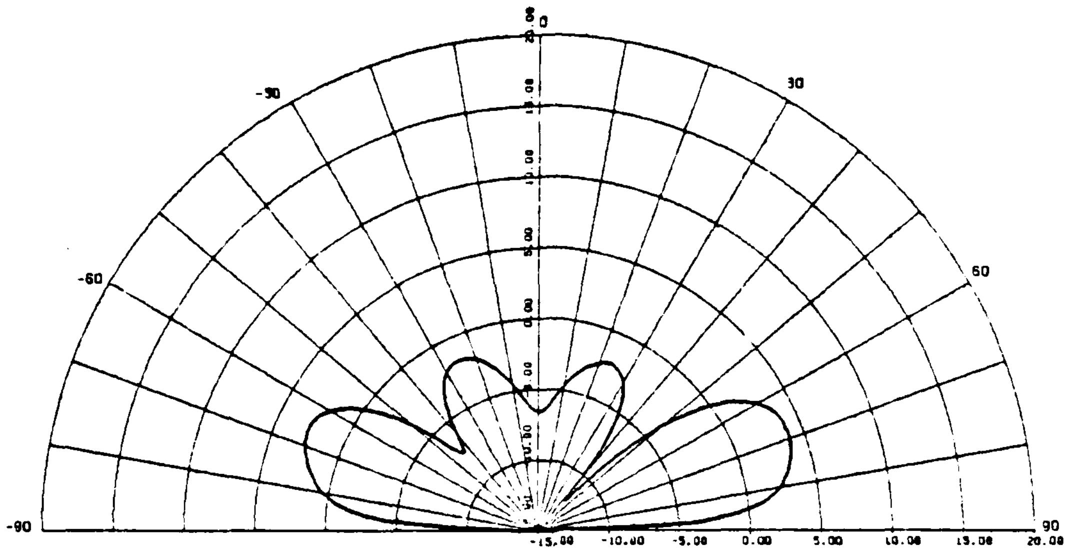
MRC-109 / THETA / PHI = 30

WET GROUND / BASIC / 75 MHZ



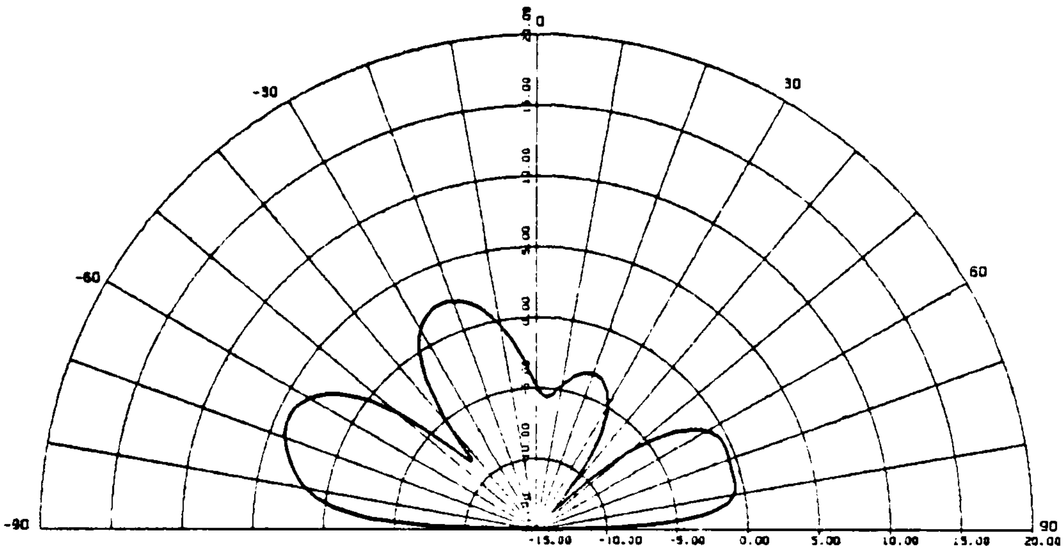
MAC-109 / THETA / PHI = 180

WET GROUND / BASIC / 75 MHZ



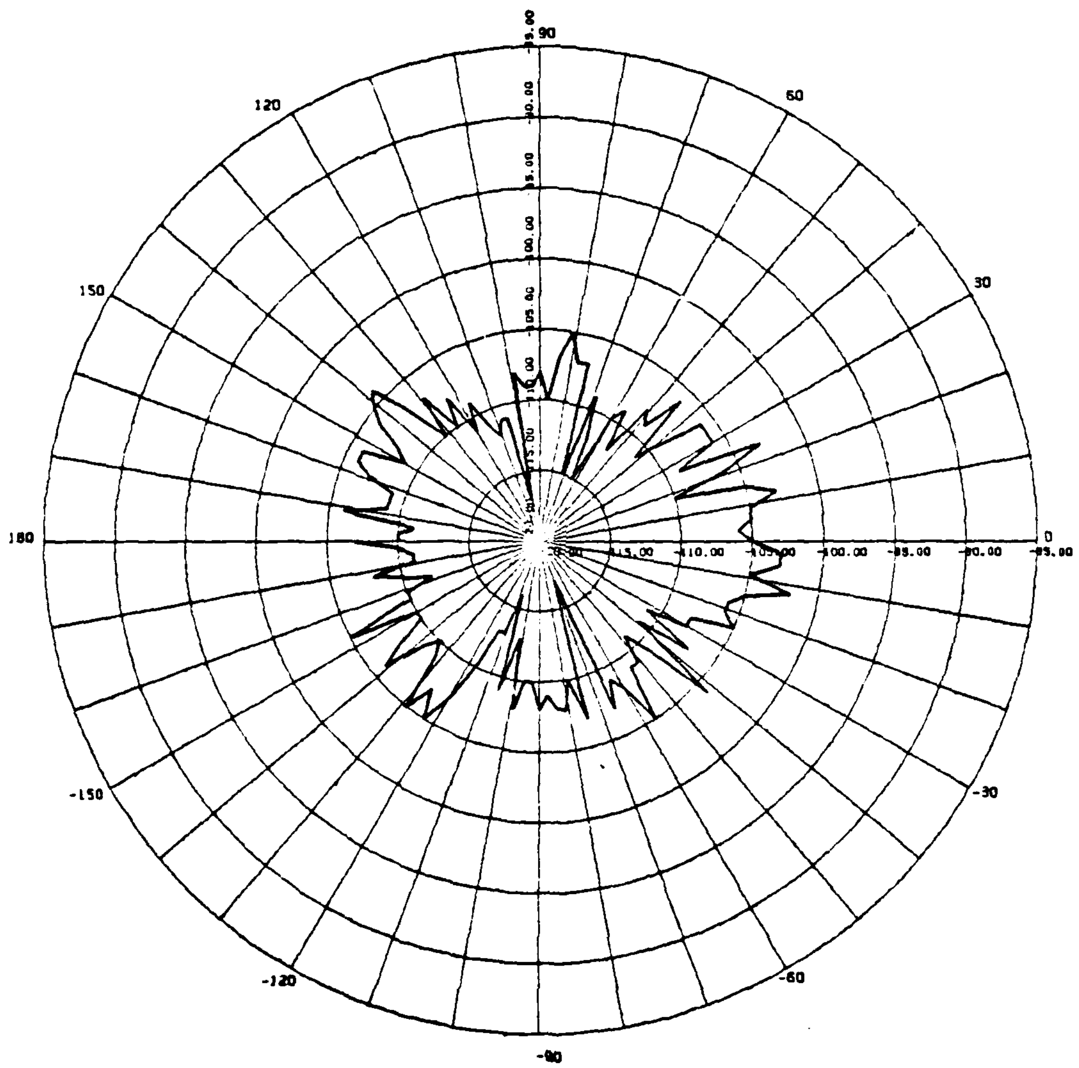
MAC-109 / THETA / PHI = 120

WET GROUND / BASIC / 75 MHZ



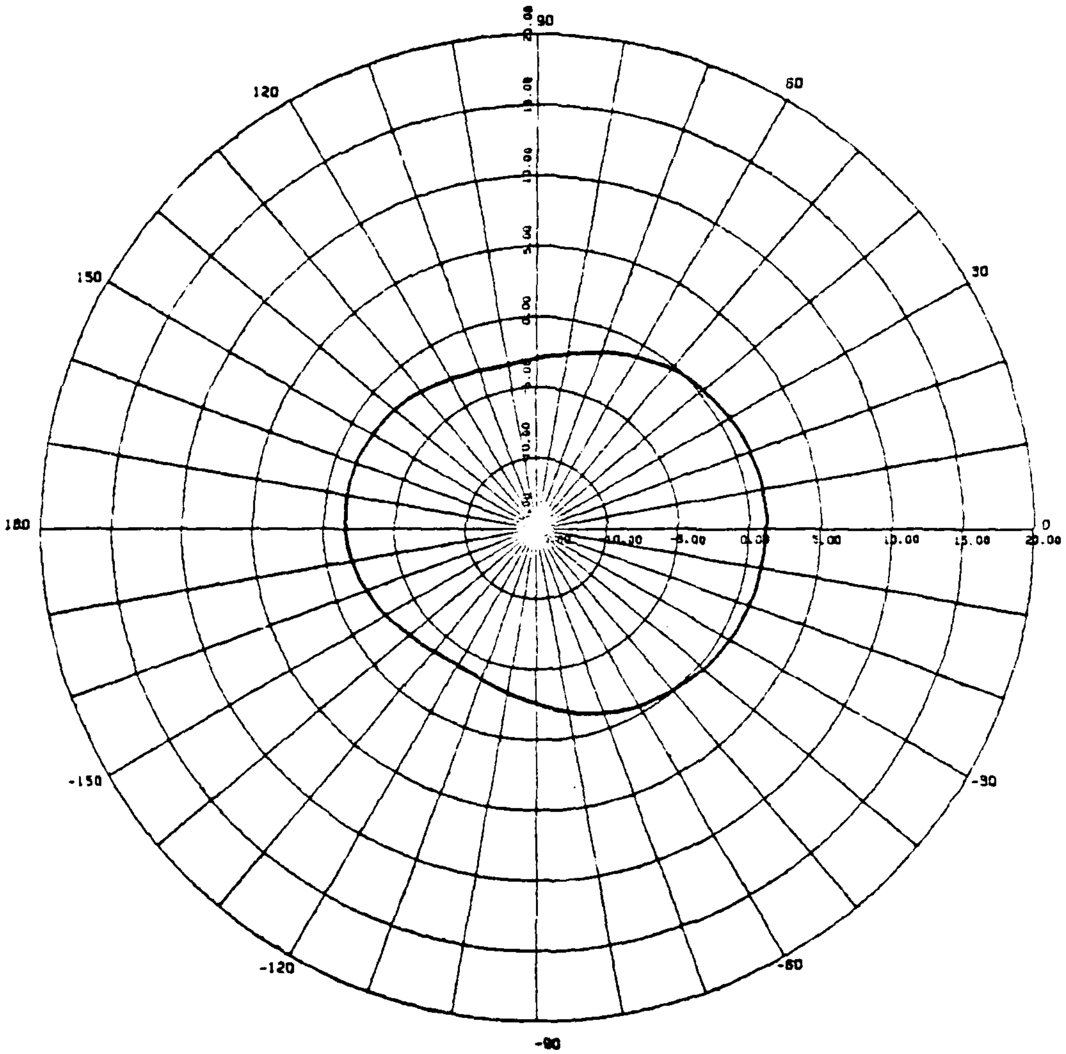
MAC-109 / PHI / THETA=90

WET GROUND / JEEP / 30 MHZ



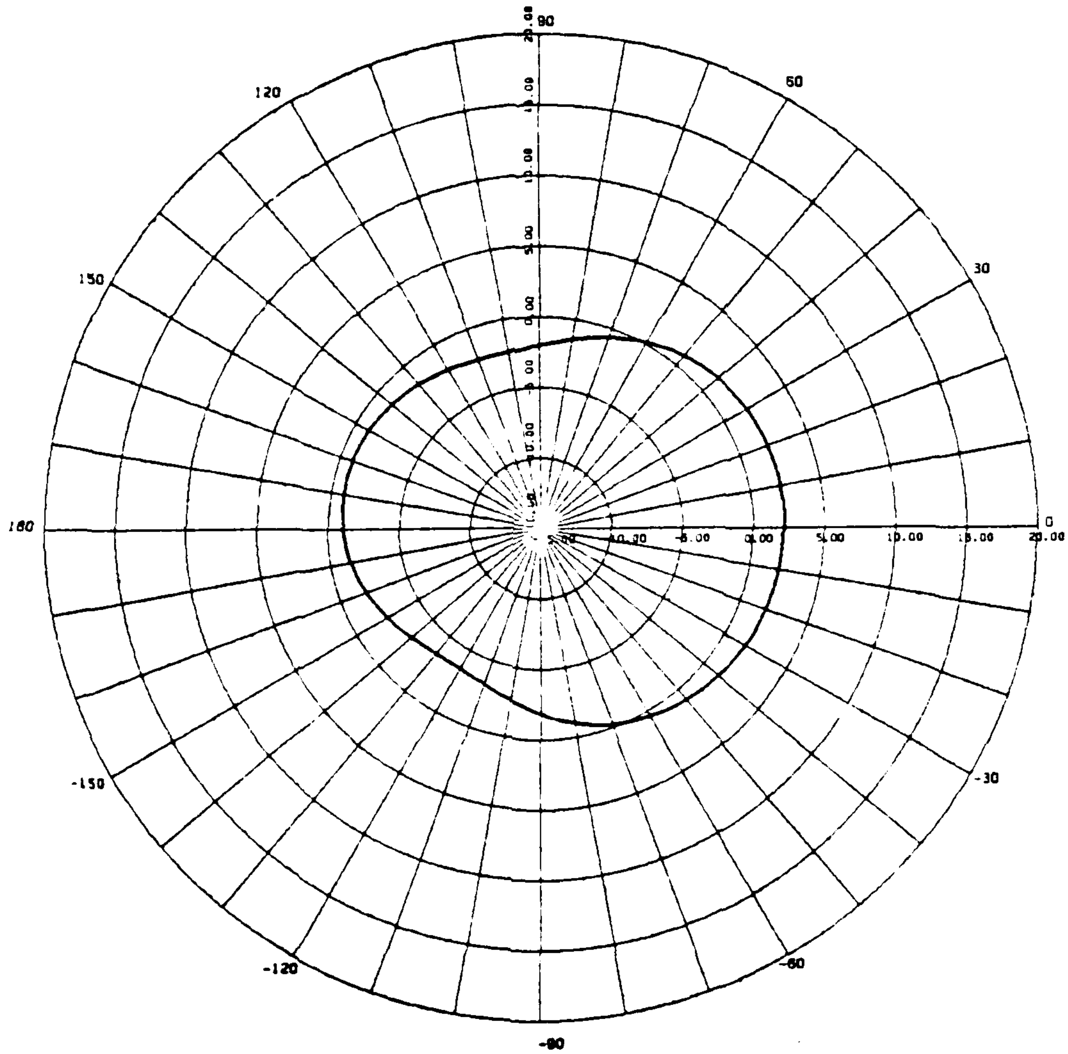
MAC-109 / PHI / THETA= 80

WET GROUND / JEEP / 30 MHZ



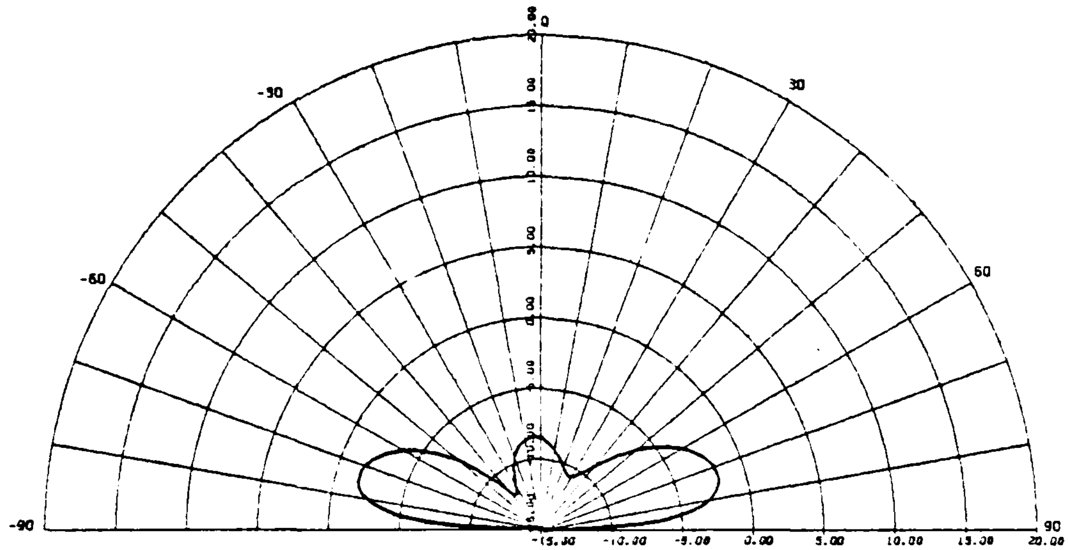
MAC-109 / PHI / THETA= 70

WET GROUND / JEEP / 30 MHZ



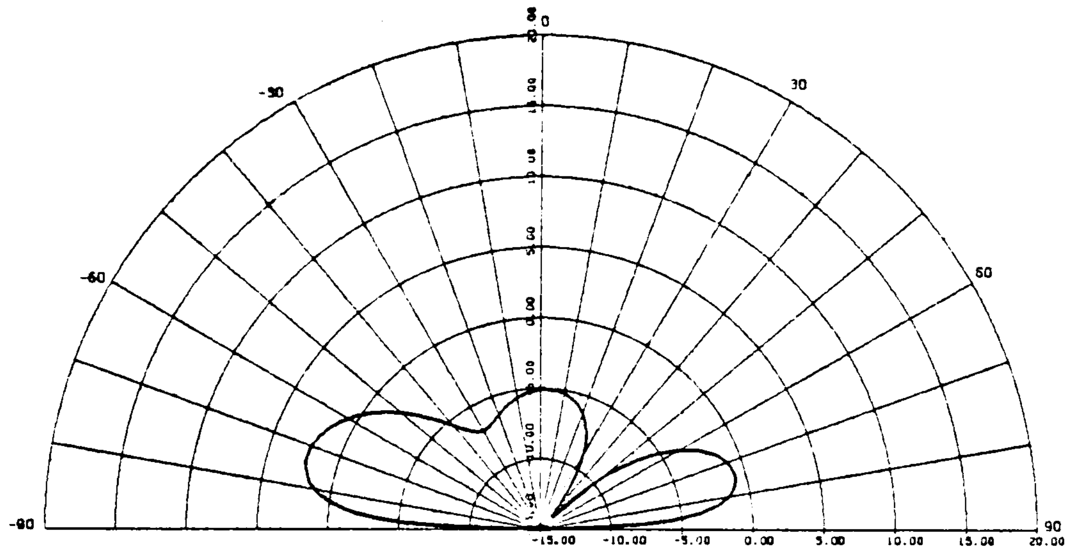
MRC-109 / THETA / PHI = 90

WET GROUND / JEEP / 30 MHZ



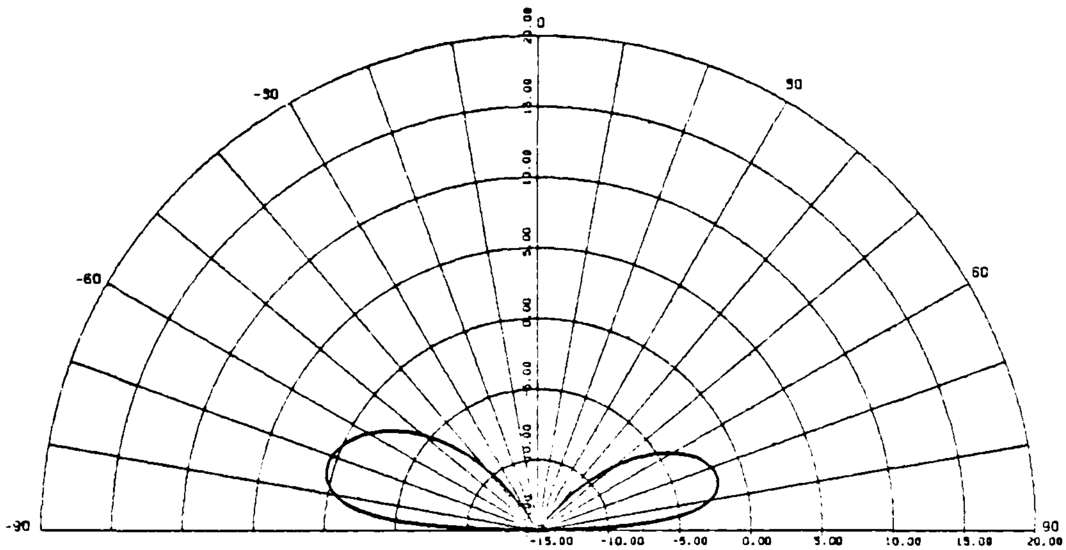
MRC-108 / THETA / PHI = 180

WET GROUND / JEEP / 30 MHZ



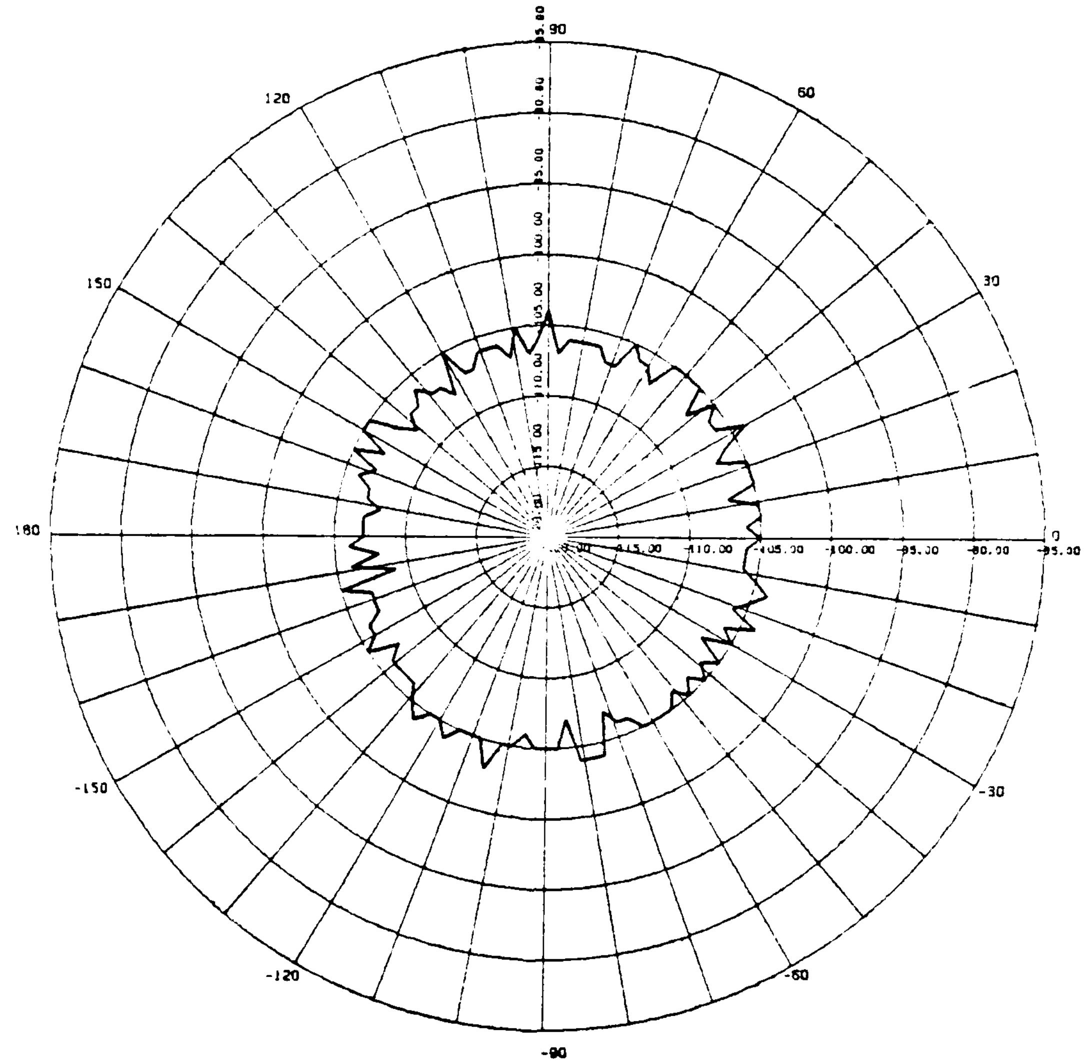
MRC-109 / THETA / PHI = 120

WET GROUND / JEEP / 30 MHZ



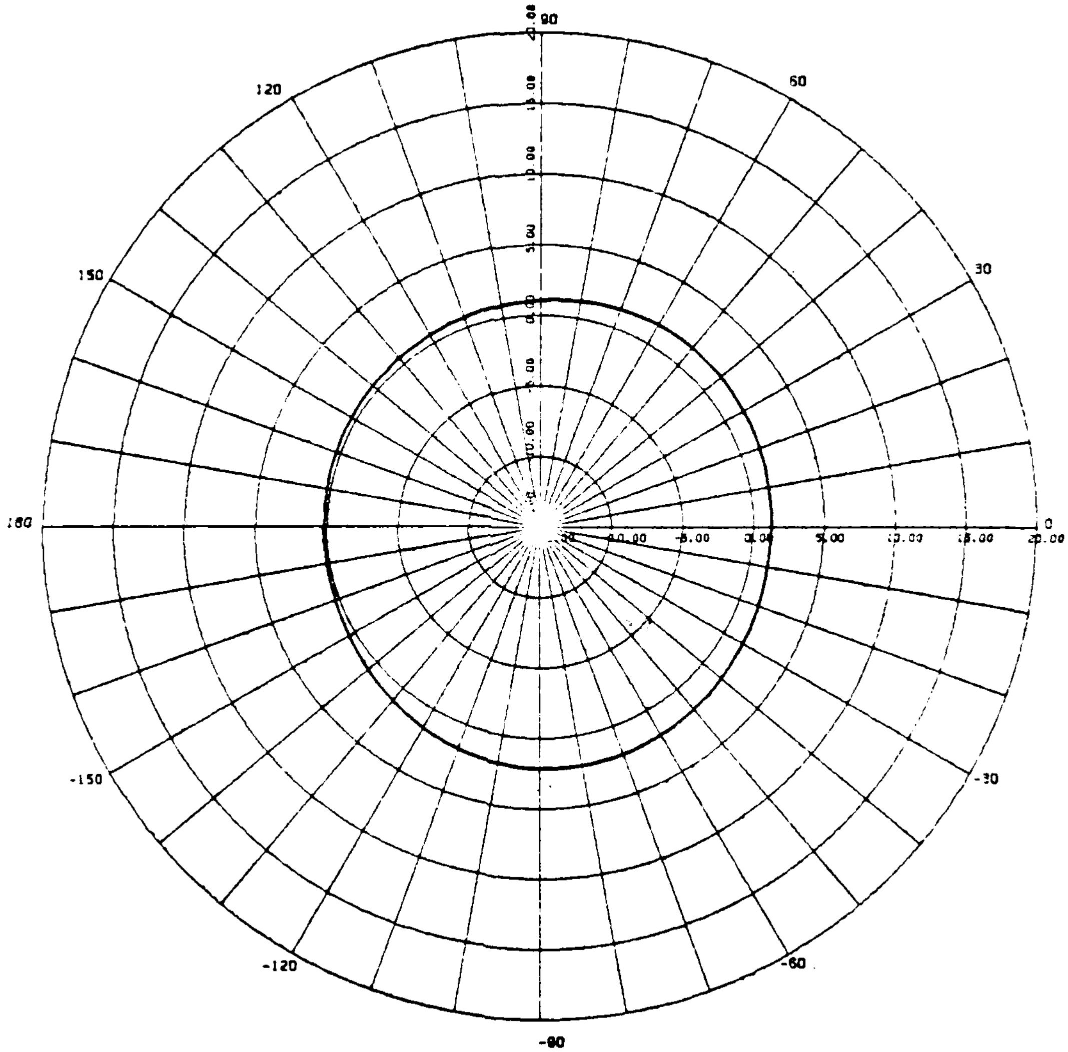
MRC-109 / PHI / THETA=90

WET GROUND / JEEP / 41 MHZ



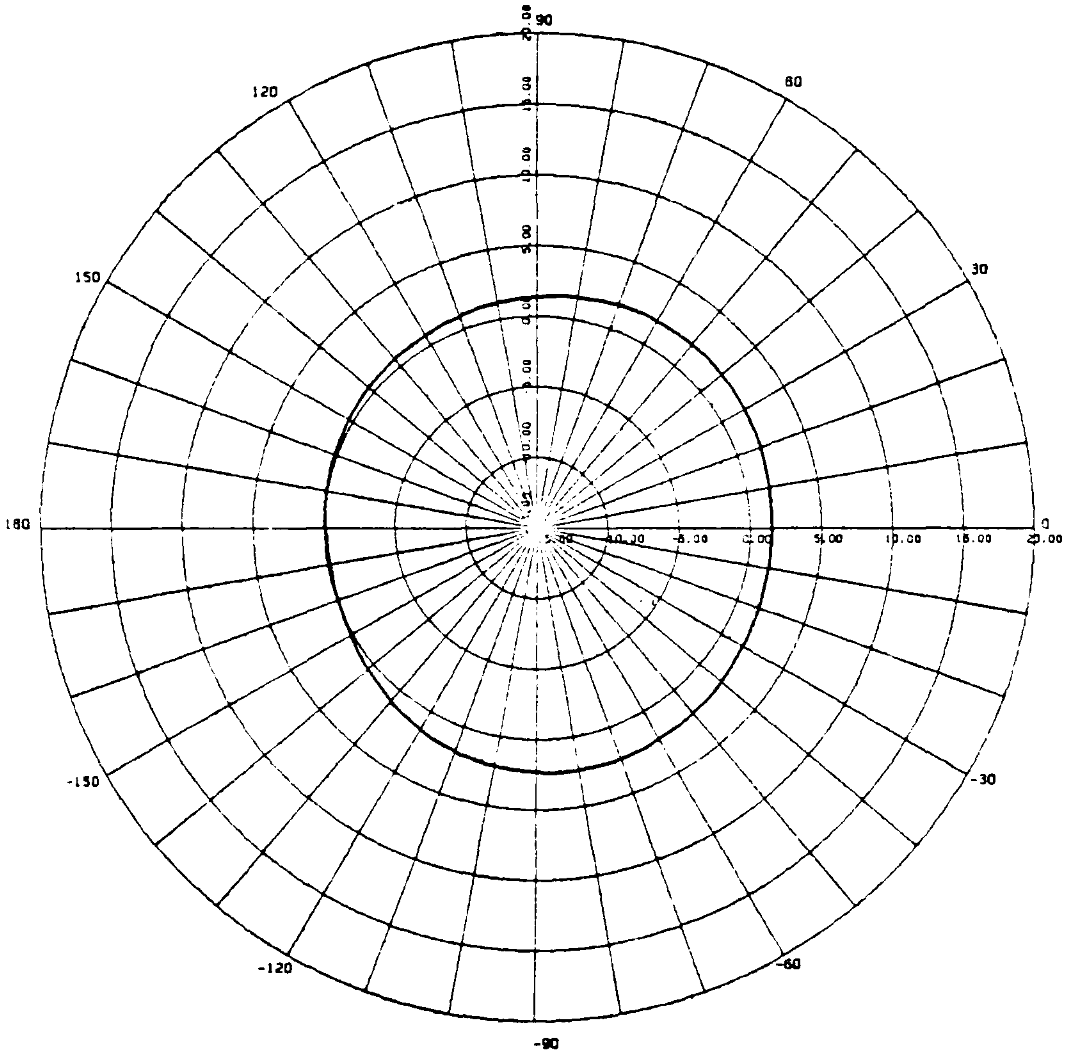
MRC-103 / PHI / THETA= 80

WET GROUND / JEEP / 41 MHZ



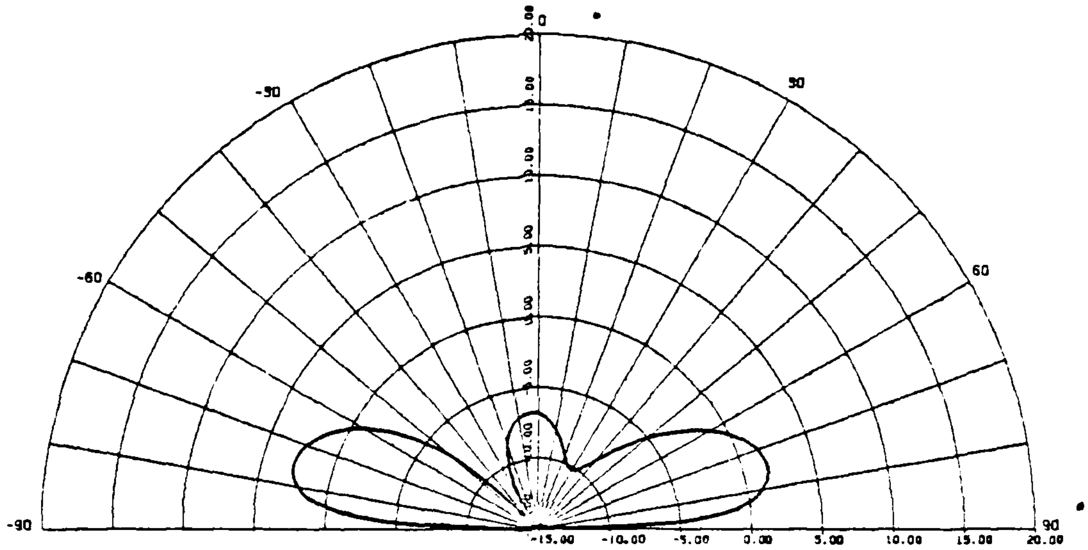
MAC-109 / PHI / THETA= 70

WET GROUND / JEEP / 41 MHZ



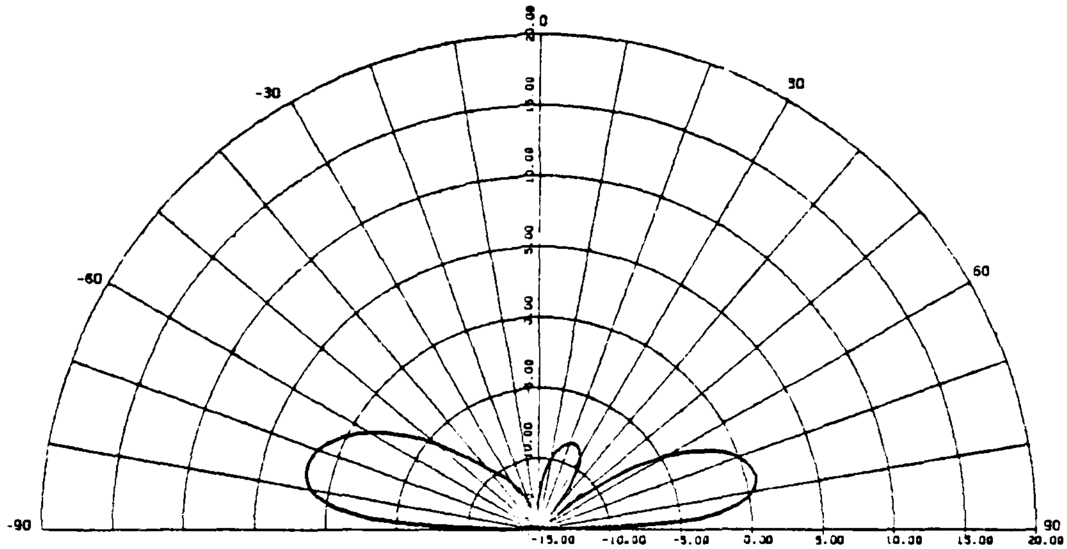
MRC-109 / THETA / PHI = 90

WET GROUND / JEEP / 41 MHZ



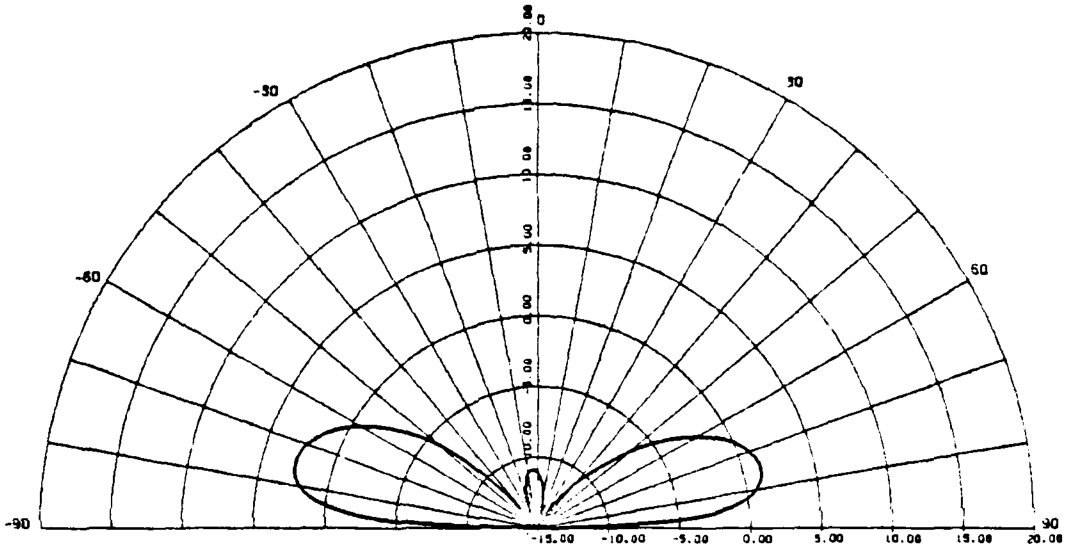
MRC-109 / THETA / PHI = 180

WET GROUND / JEEP / 41 MHZ



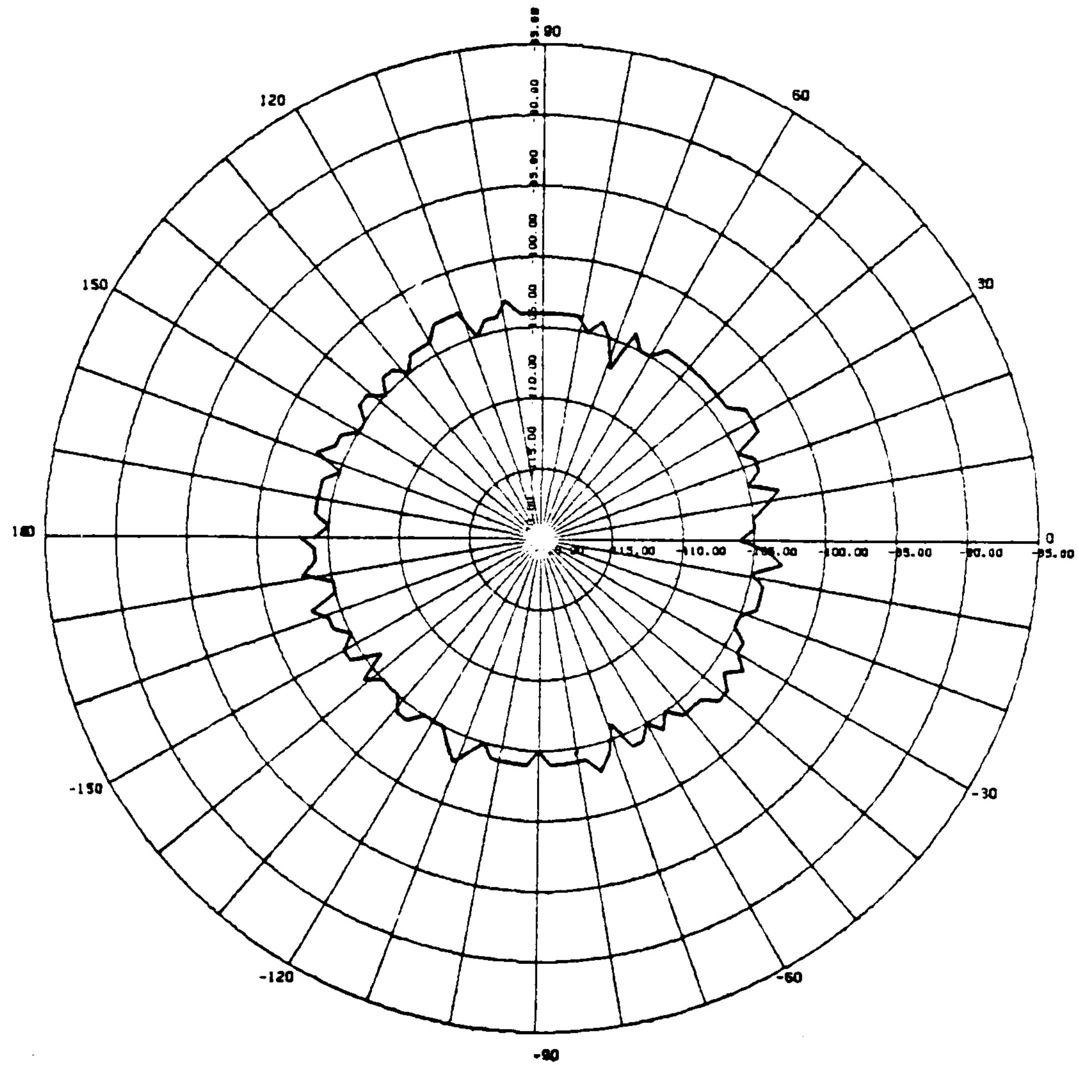
MRC-109 / THETA / PHI = 120

WET GROUND / JEEP / 41 MHZ



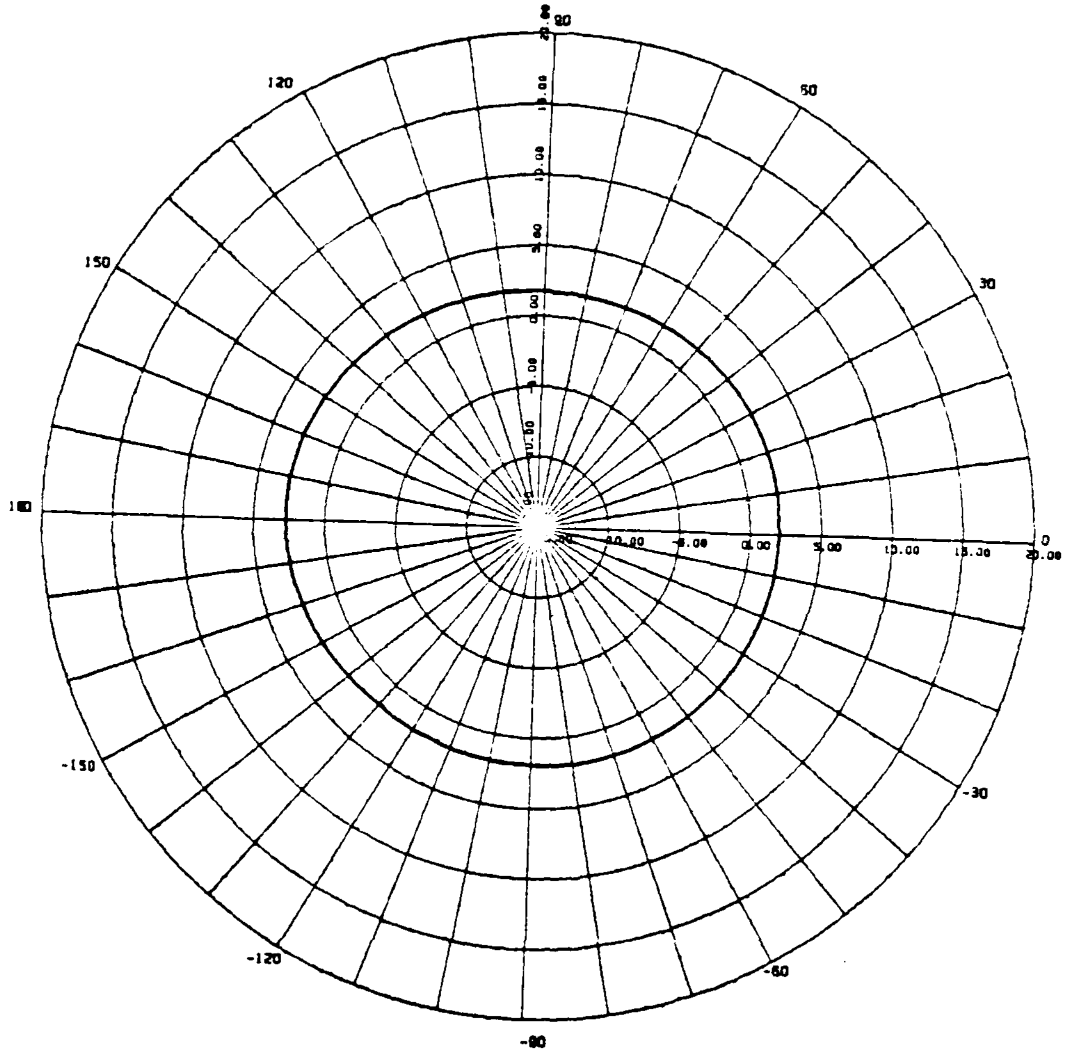
MAC-10S / PHI / THETA=90

WET GROUND / JEEP / 50 MHZ



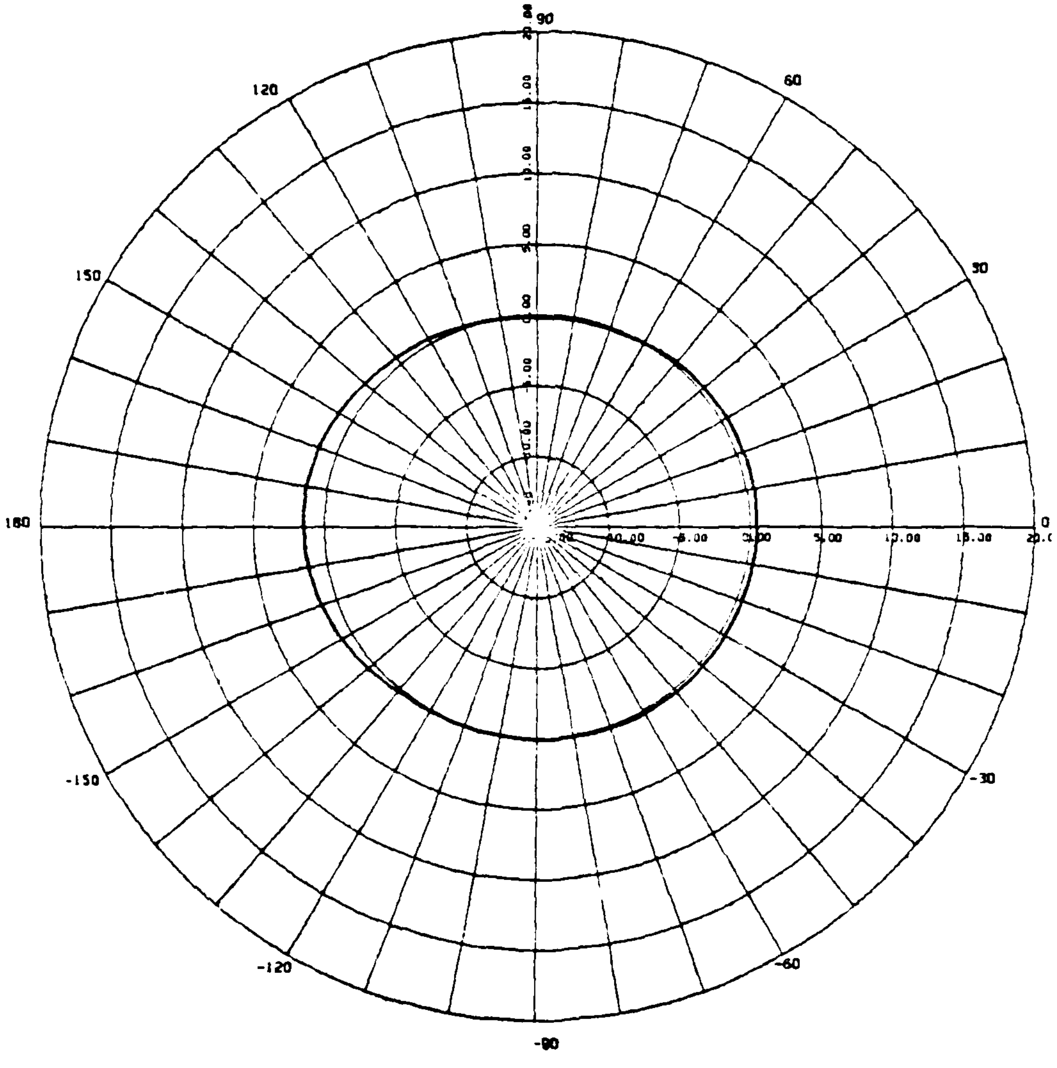
MRC-109 / PHI / THETA= 80

WET GROUND / JEEP / 50 MHZ



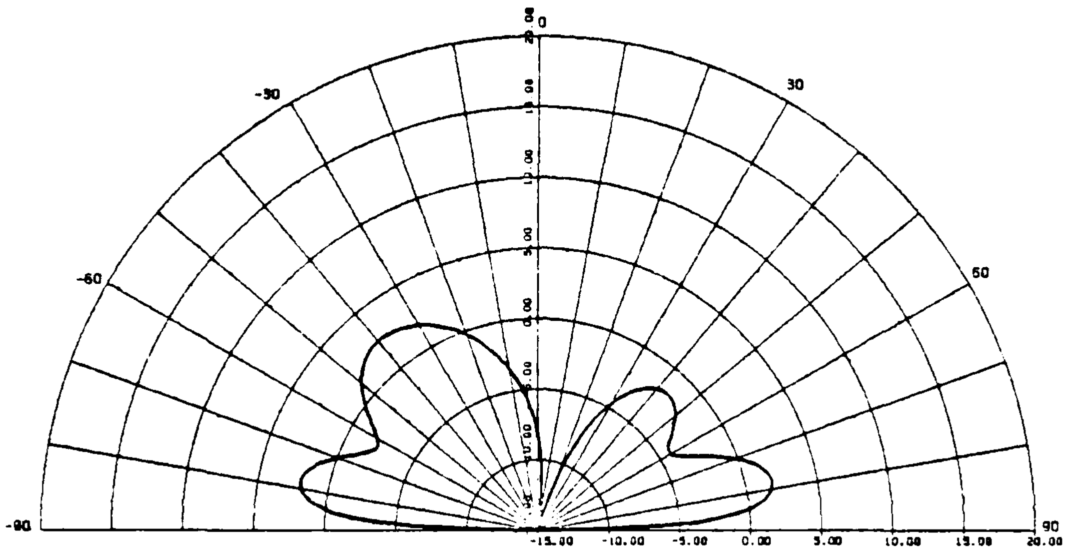
MAC-109 / PHI / THETA= 70

WET GROUND / JEEP / 50 MHZ



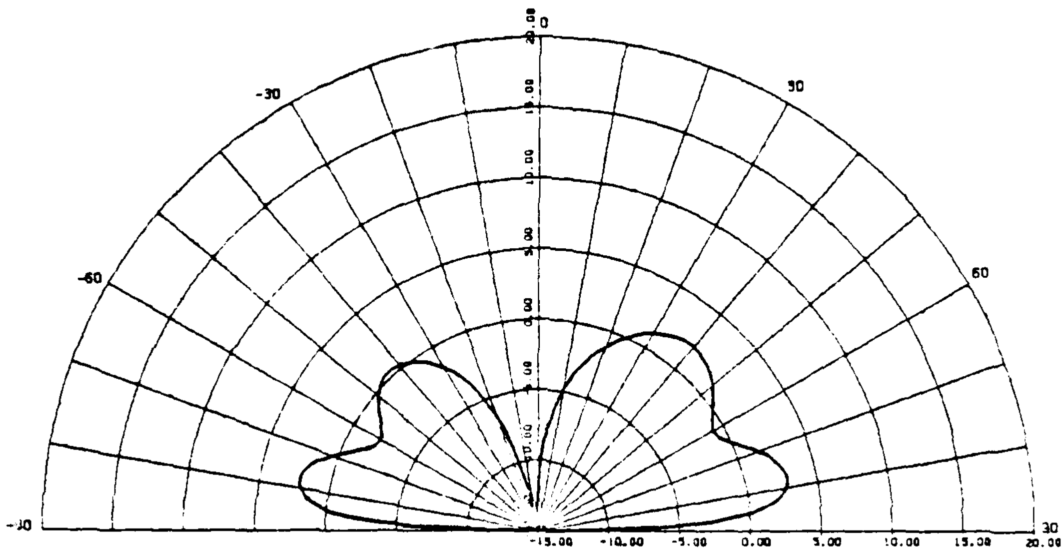
MRC-109 / THETA / PHI = 90

WET GROUND / JEEP / 50 MHZ



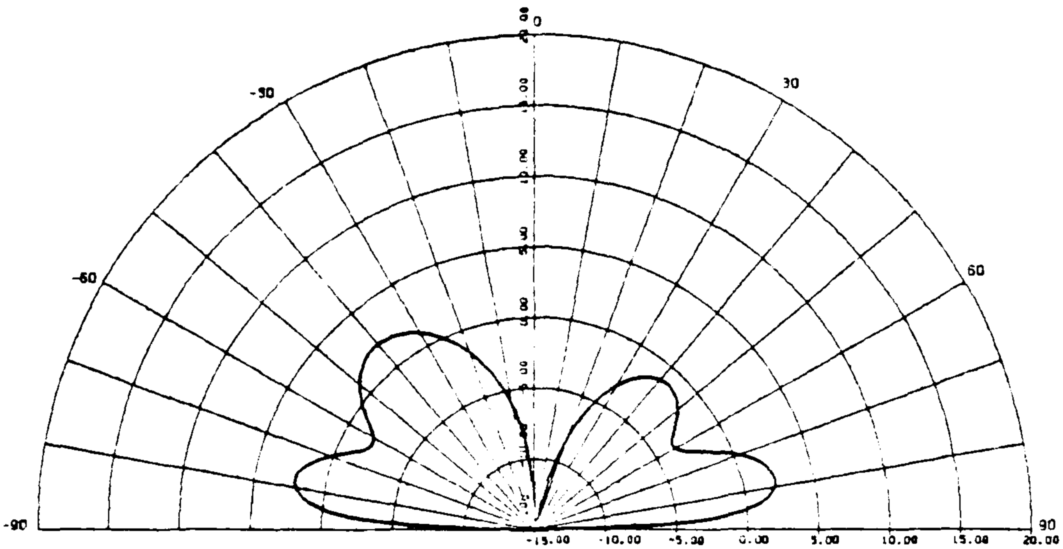
MRC-1[illegible] / THETA / PHI = 180

WET GROUND / JEEP / 50 MHZ



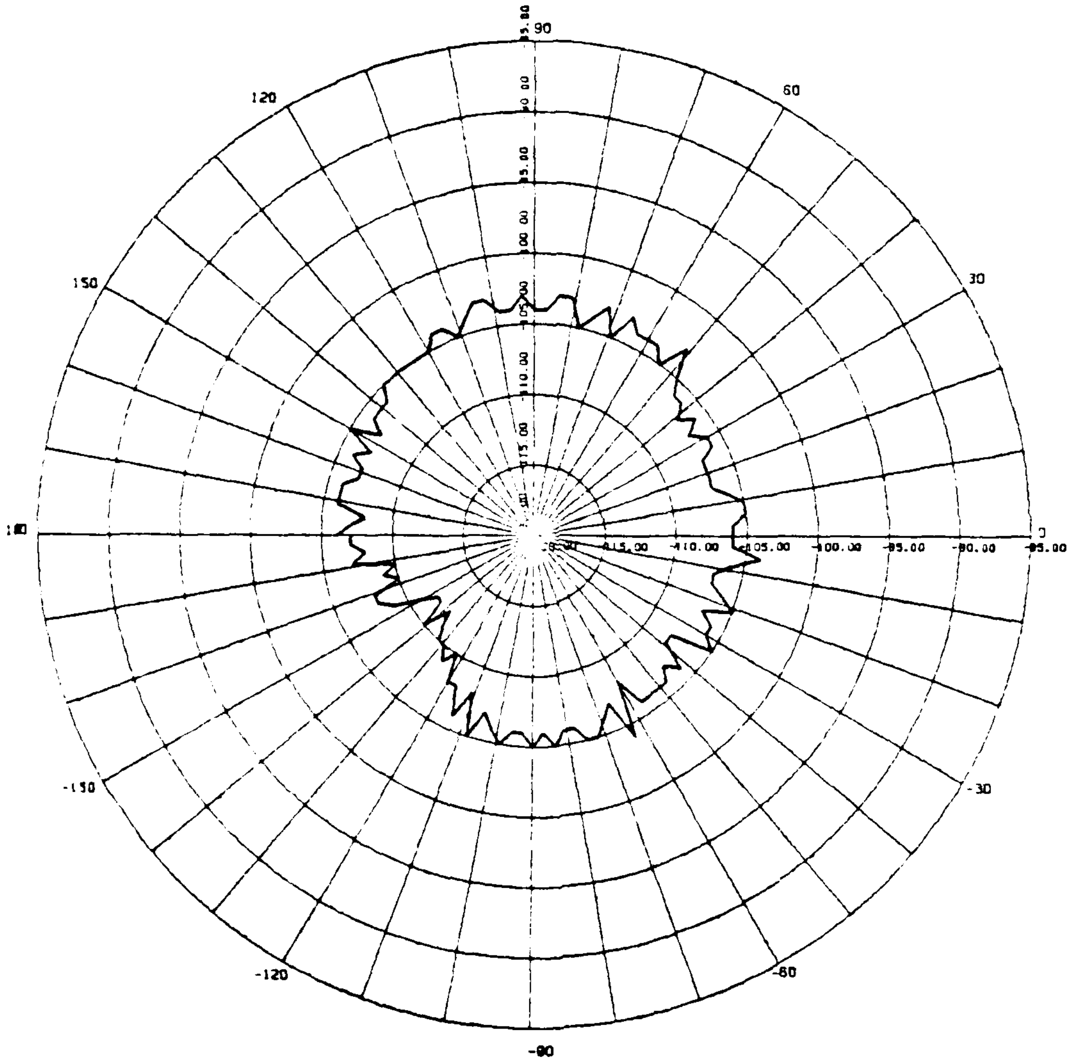
MRC-109 / THETA / PHI = 120

WET GROUND / JEEP / 50 MHZ



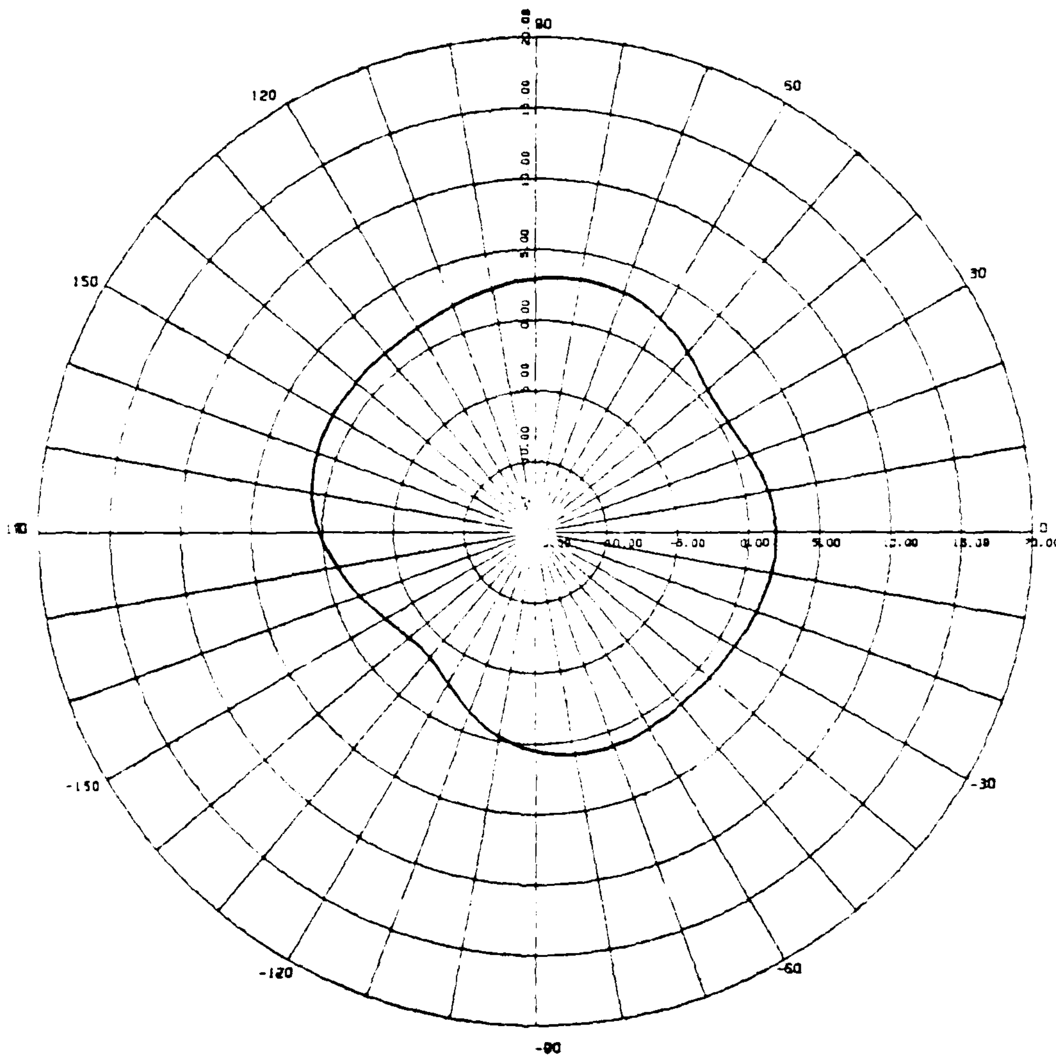
MRC-109 / PHI / THETA=90

WET GROUND / JEEP / 75 MHZ



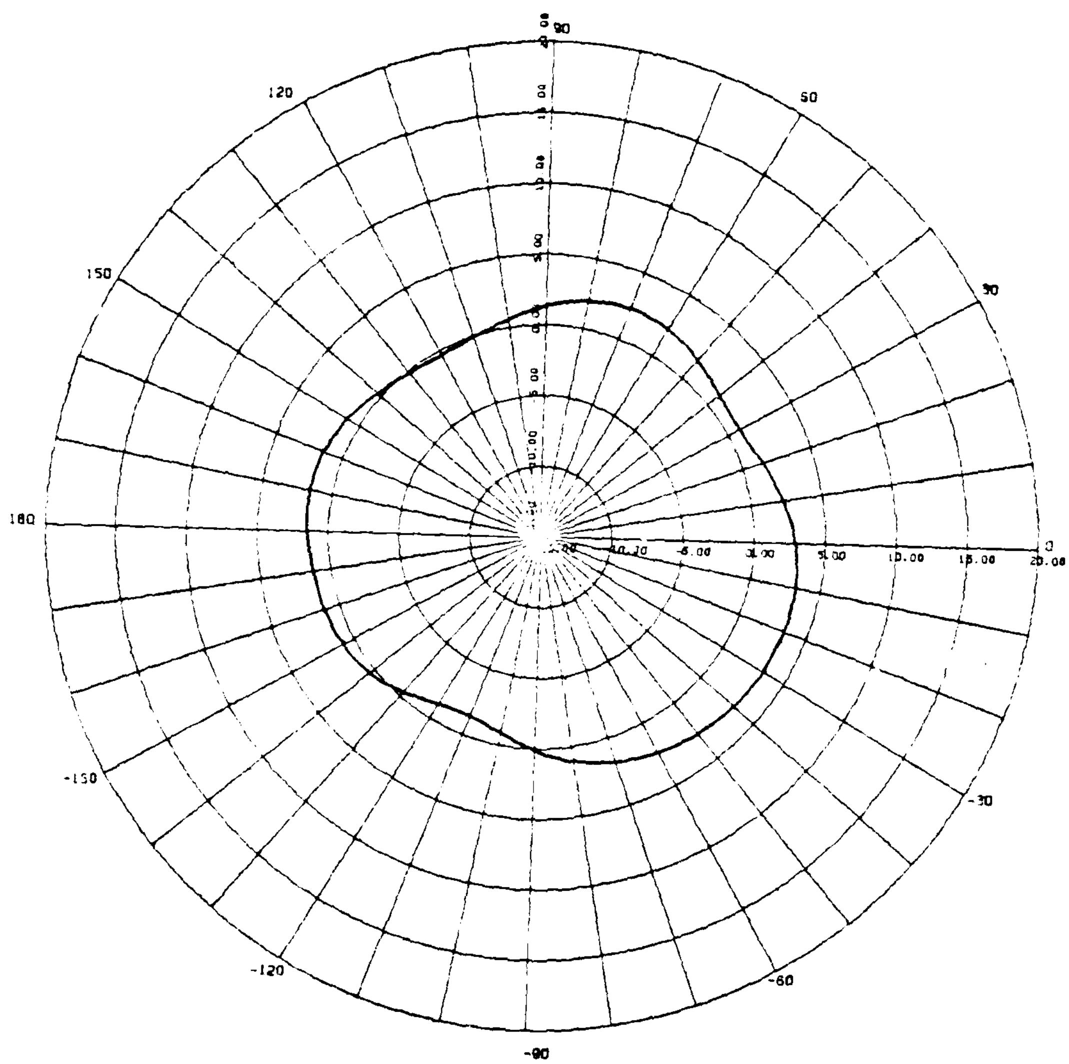
MRC-108 / PHI / THETA= 80

WET GROUND / JEEP / 75 MHZ



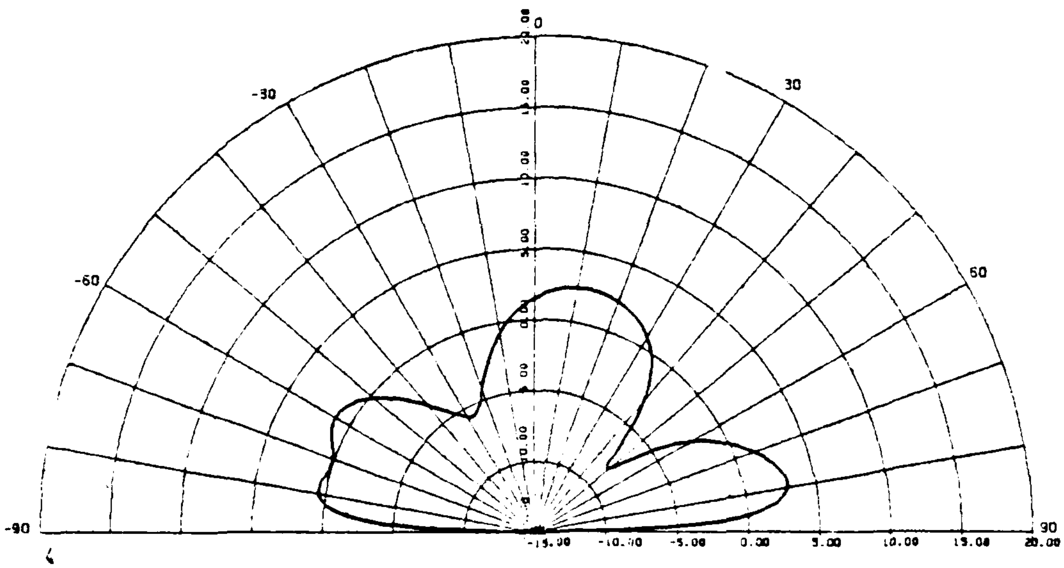
MRC-108 / PHI / THETA= 70

WET GROUND / JEEP / 75 MHZ



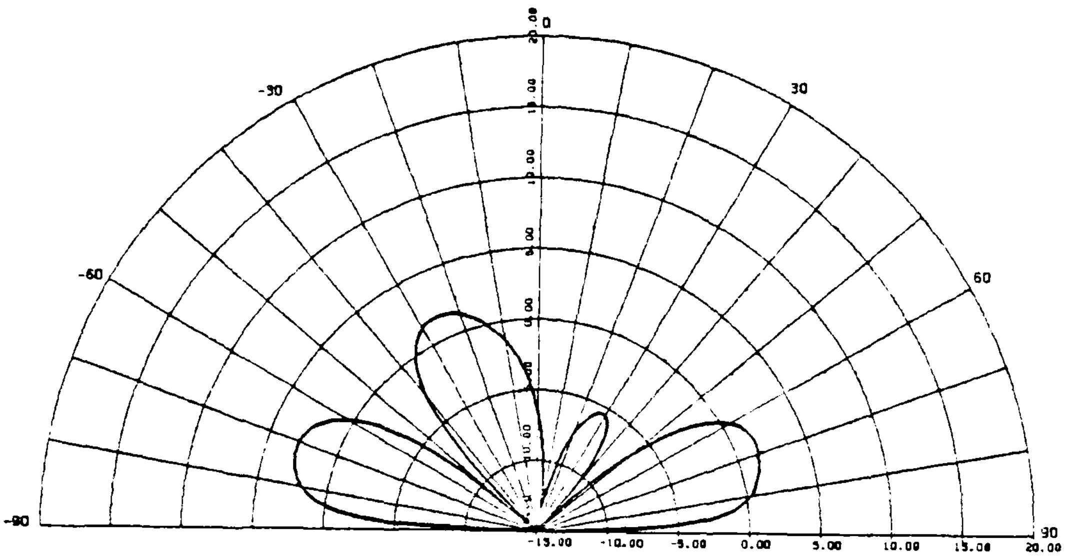
MRC-109 / THETA / PHI = 90

WET GROUND / JEEP / 75 MHZ



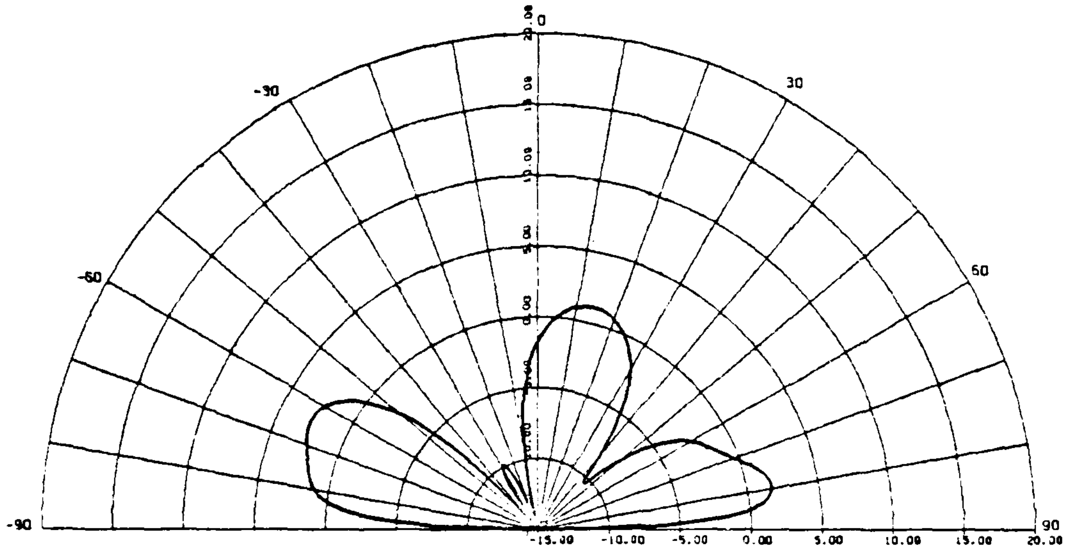
MRC-109 / THETA / PHI = 180

WET GROUND / JEEP / 75 MHZ



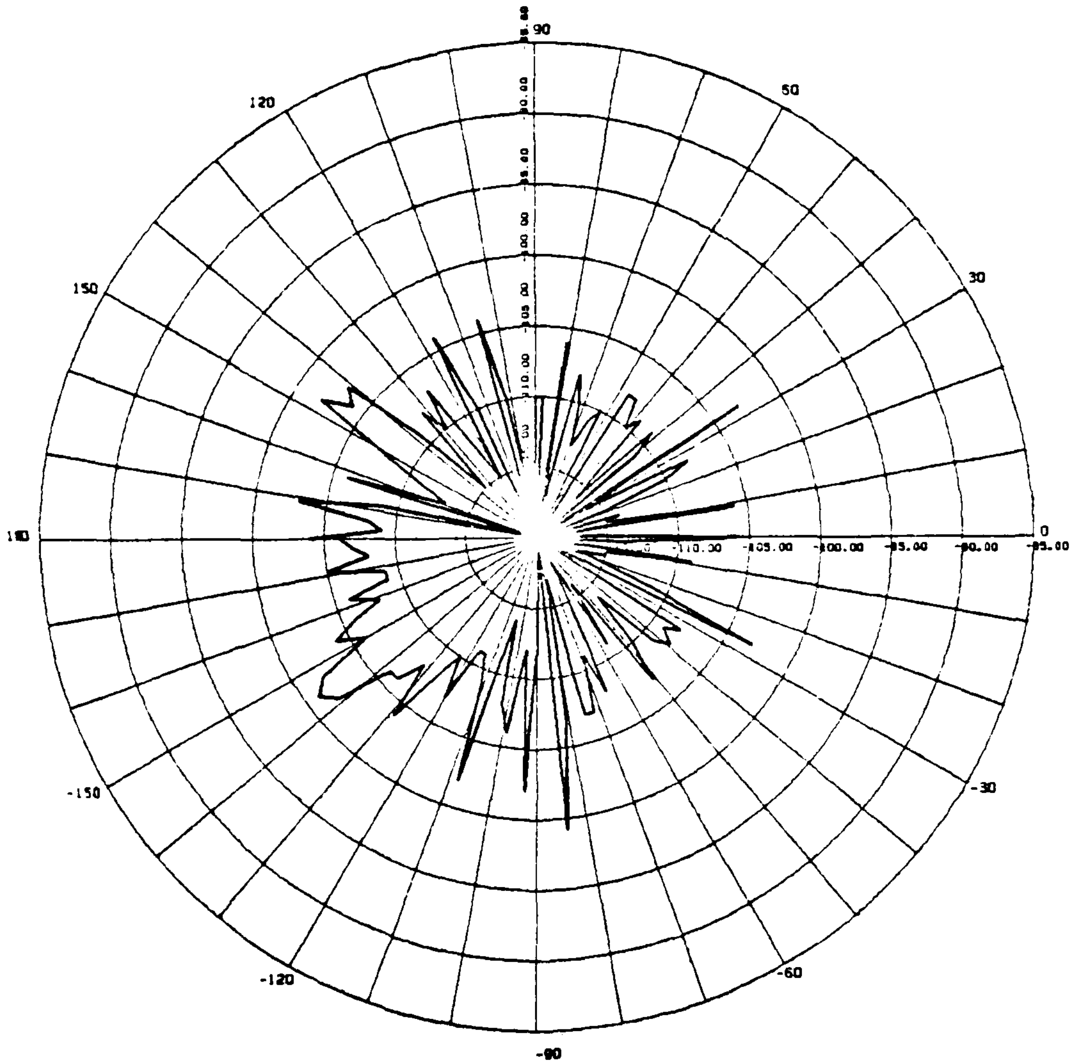
MRC-109 / THETA / PHI = 120

WET GROUND / JEEP / 75 MHZ



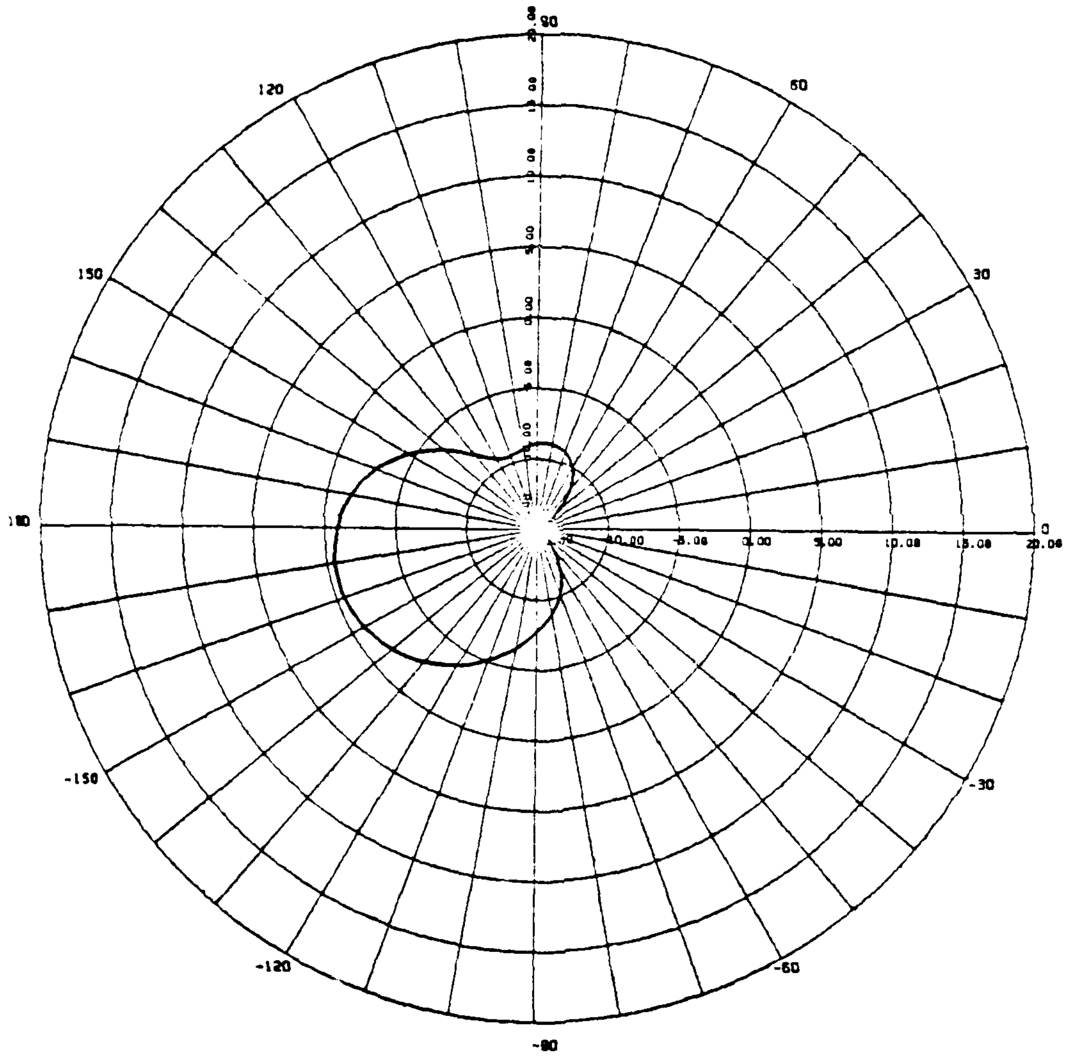
MAC-109 / PHI / THETA=90

WET GRND / JEEP & TALA / 30 MHZ



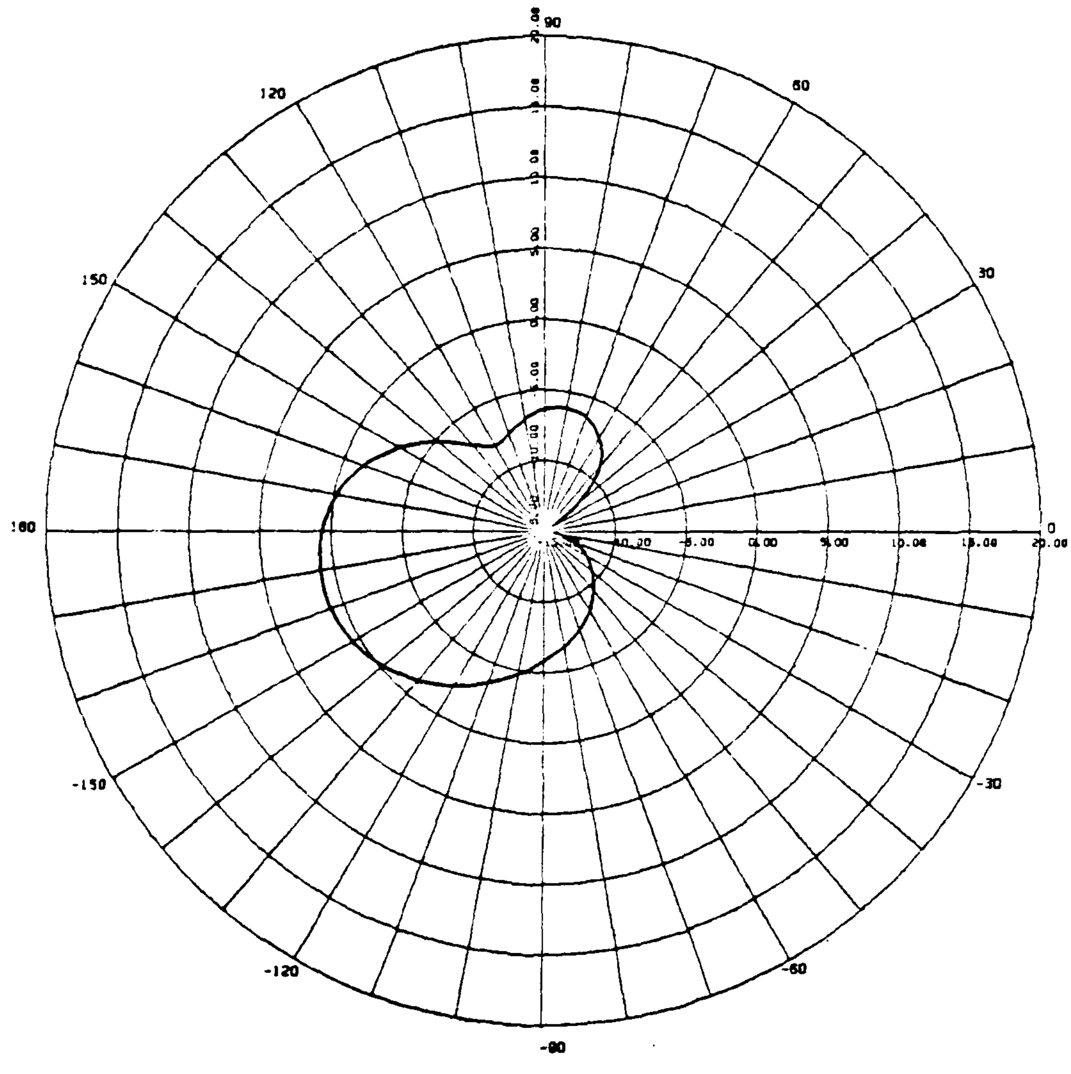
MRC-109 / PHI / THETA=80

WET GRND / JEEP & TRLR / 30 MHZ



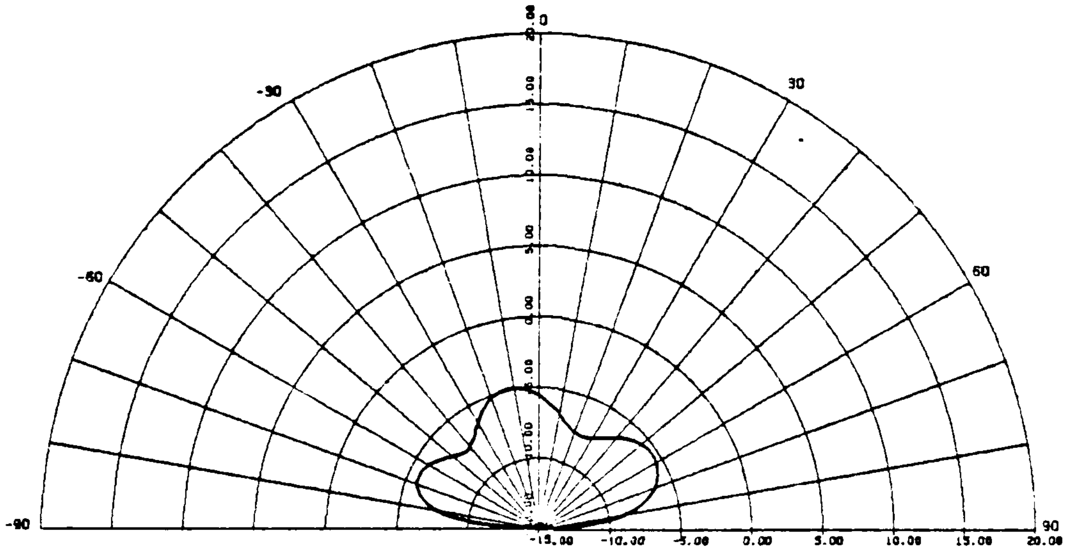
MAC-109 / PHI / THETA=70

WET GRND / JEEP & TRLR / 30 MHZ



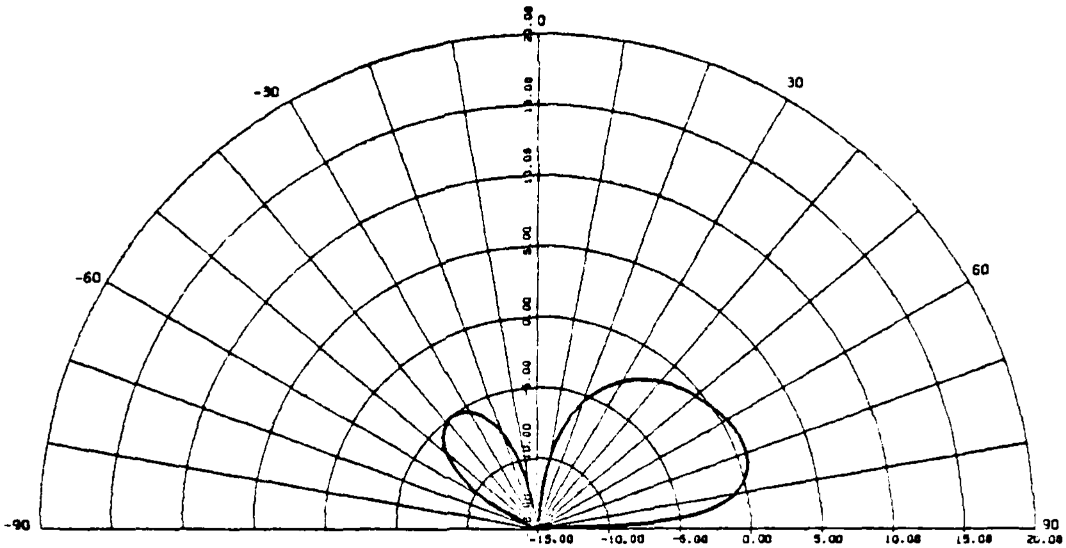
MAC-109 / THETA / PHI=90

WET GRND / JEEP & TRLR / 30 MHZ



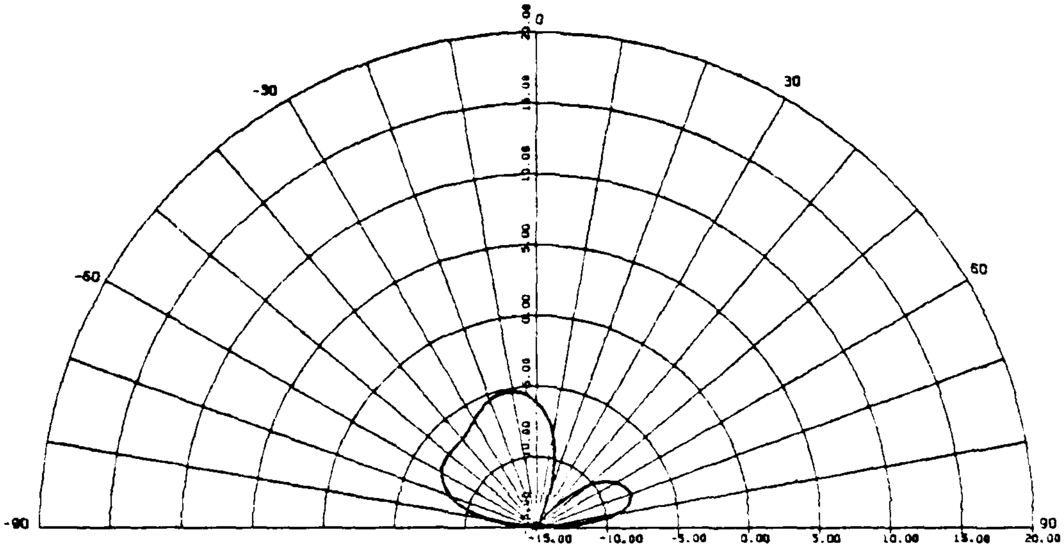
MRC-103 / THETA / PHI=180

WET GRND / JEEP & TRLR / 30 MHZ



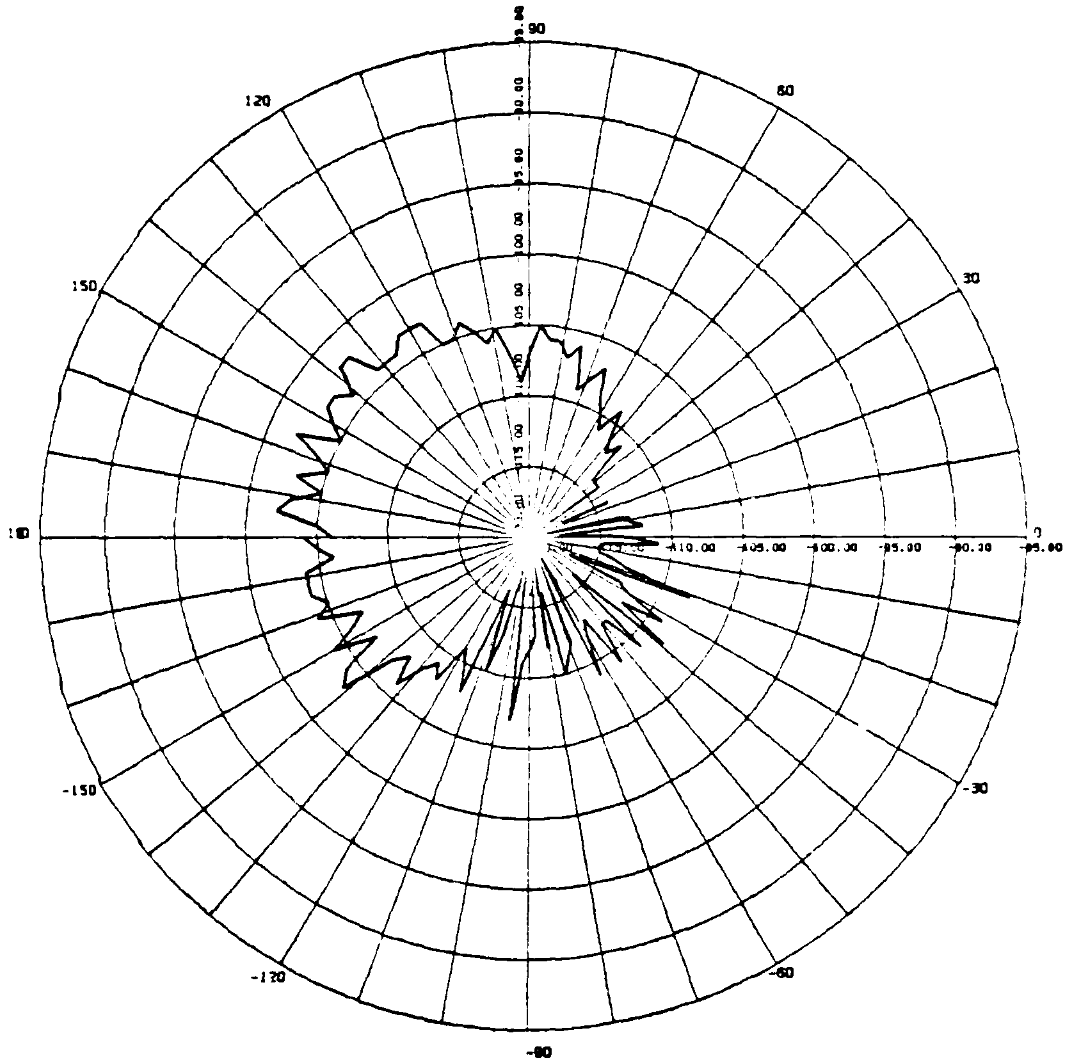
MRC-109 / THETA / PHI=120

WET GRND / JEEP & TRLR / 30 MHZ



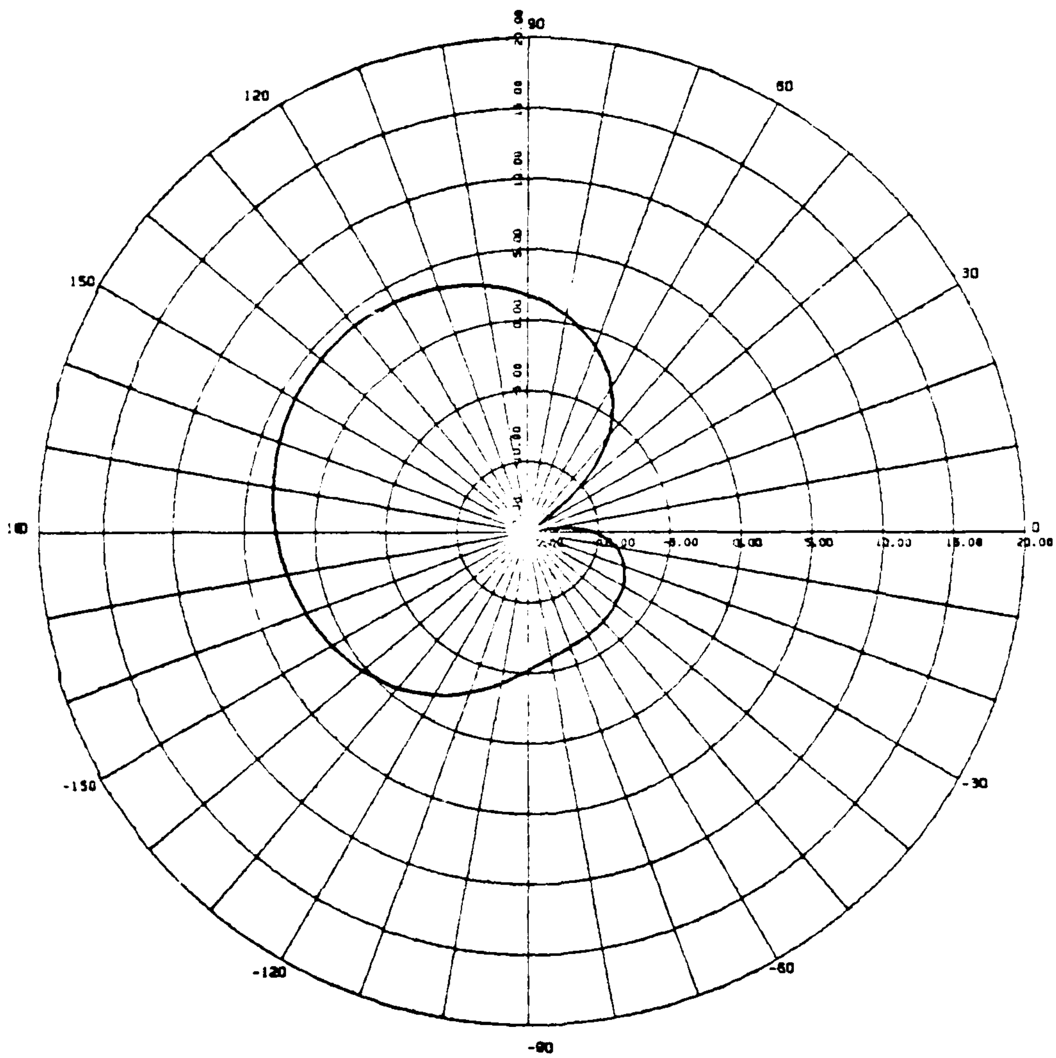
MRC-109 / PHI / THETA=90

WET GRND / JEEP & TRLR / 41 MHZ



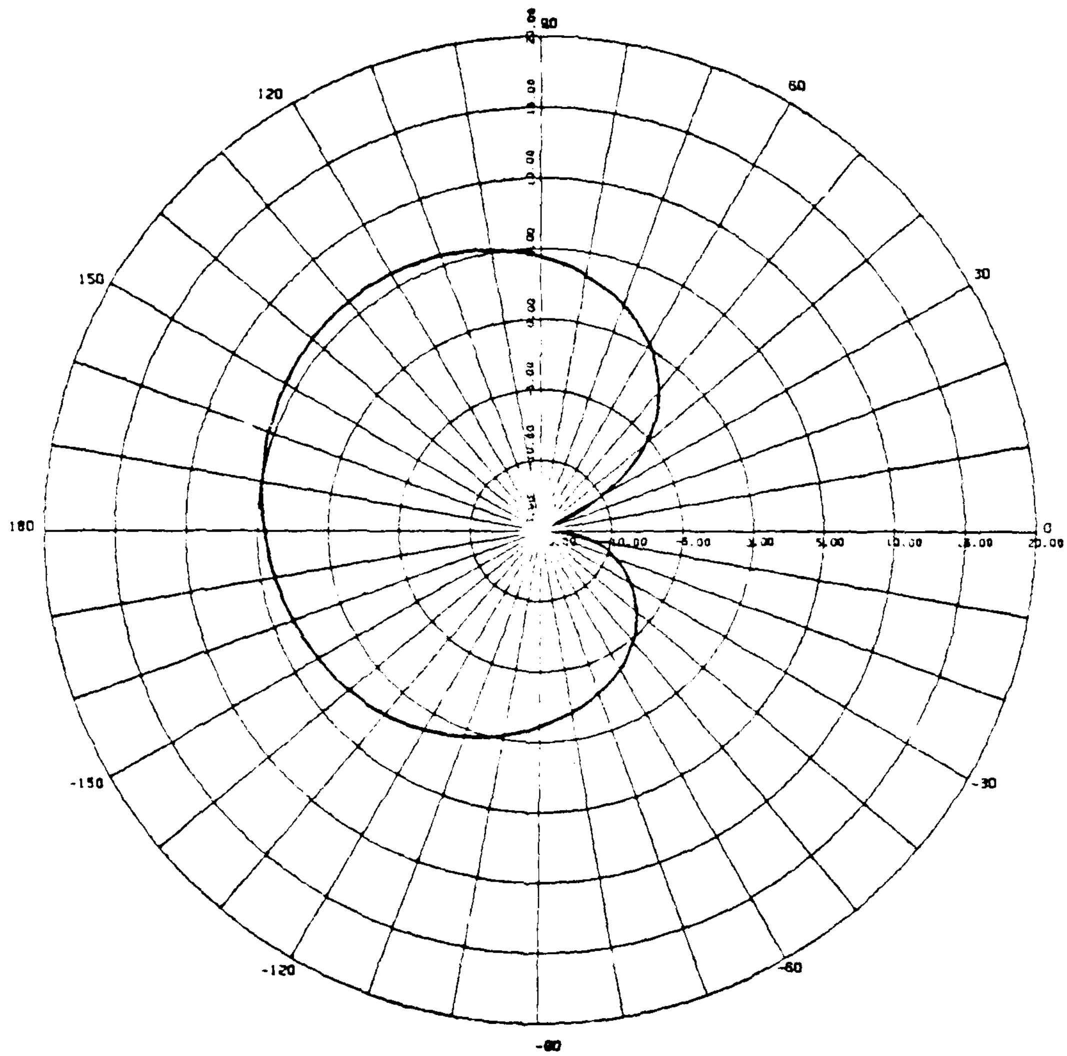
MRC-109 / PHI / THETA=80

WET SAND / JEEP & TRLR / 41 MHZ



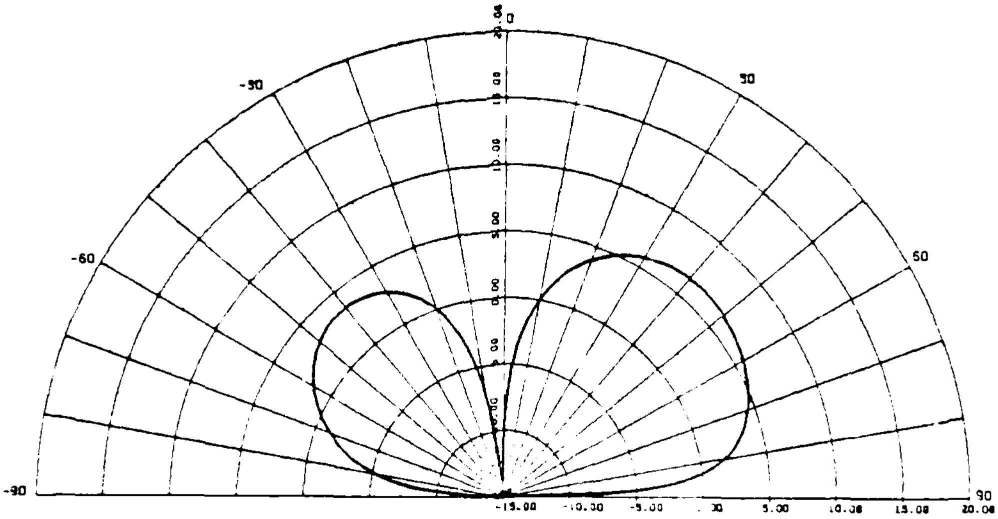
MRC-109 / PHI / THETA=70

WET GRND / JEEP & TRLR / 41 MHZ



MRC-109 / THETA / PHI=90

WET GRND / JEEP & TRLR / 41 MHZ



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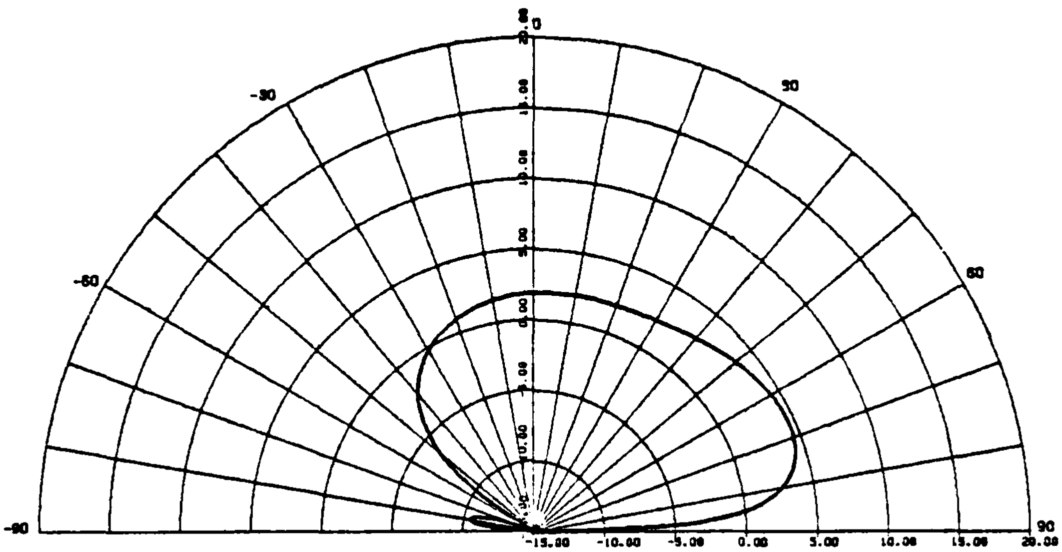
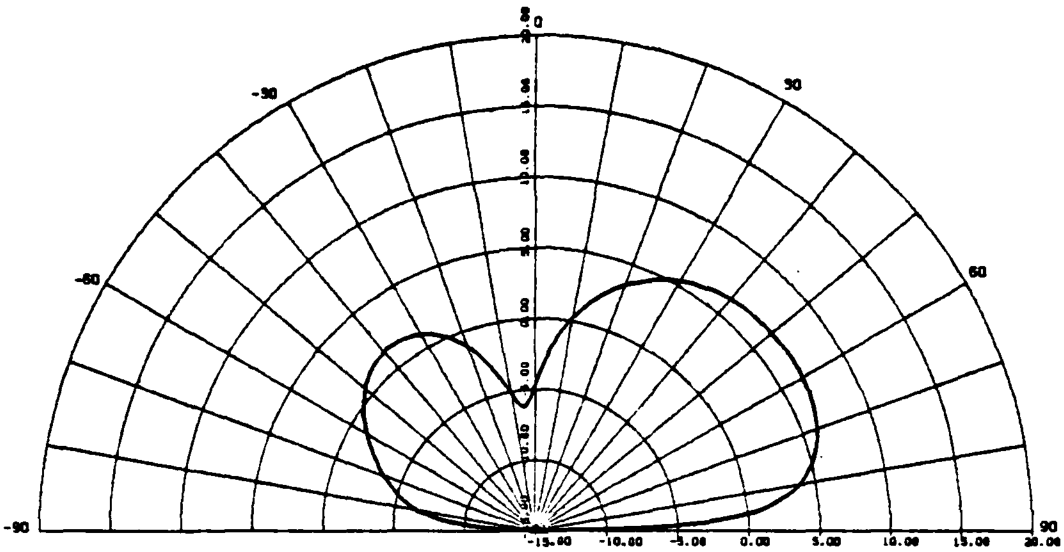
MAC-109 / THETA / PHI=180

WET GRND / JEEP & TRLR / 41 MHZ



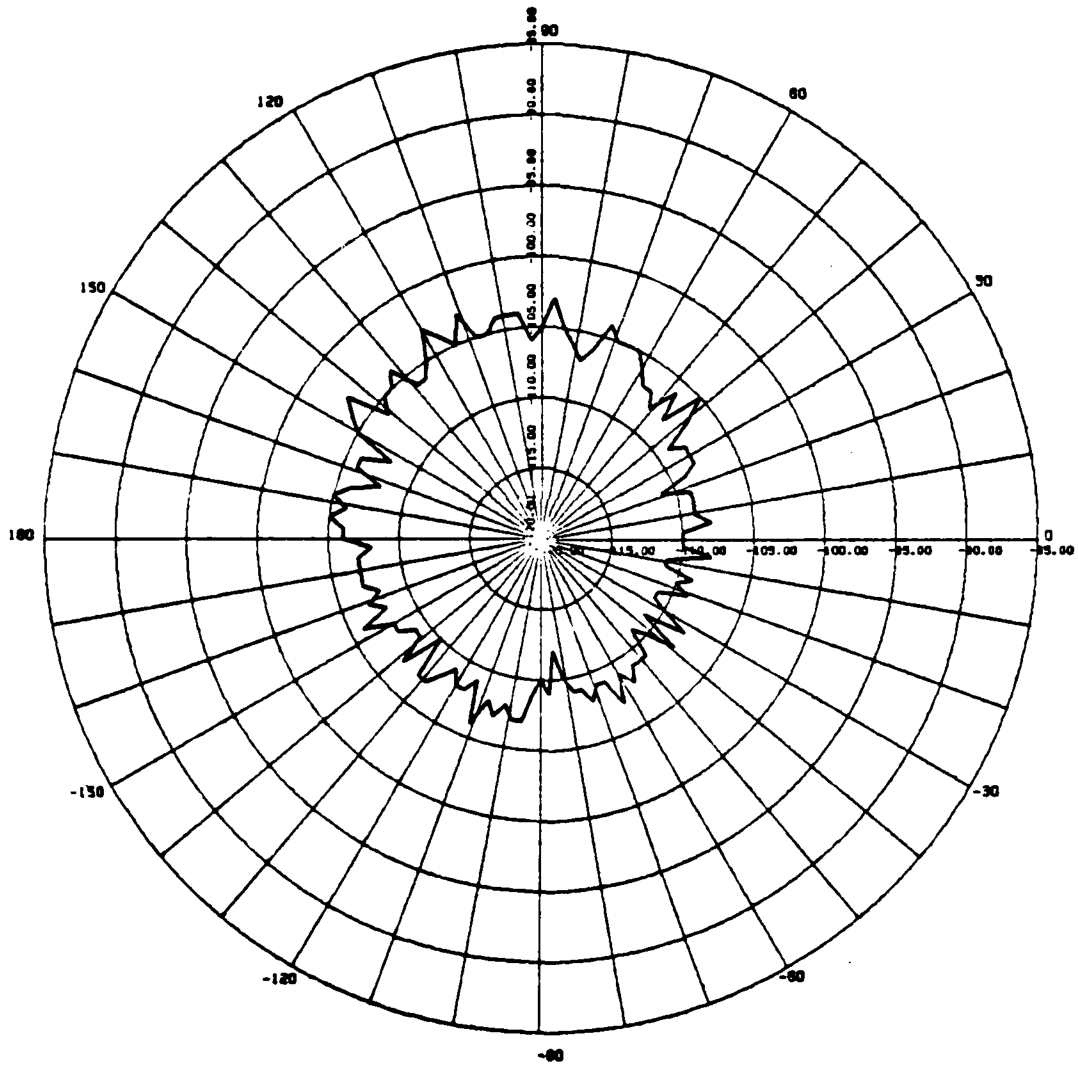
MRC-1?9 / THETA / PHI=120

WET GRND / JEEP & TALA / 41 MHZ



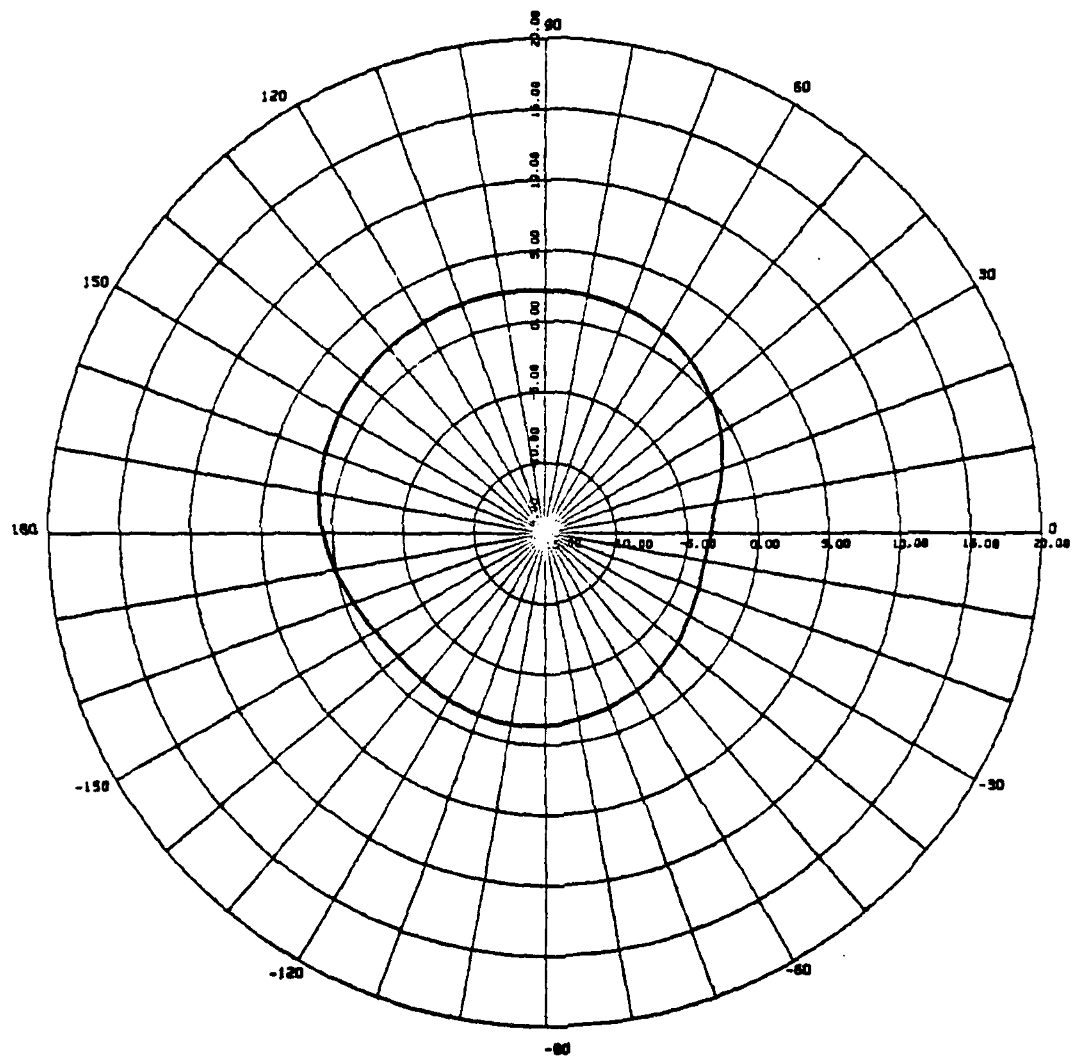
MAC-109 / PHI / THETA=90

WET GRND / JEEP & TALA / 50 MHZ



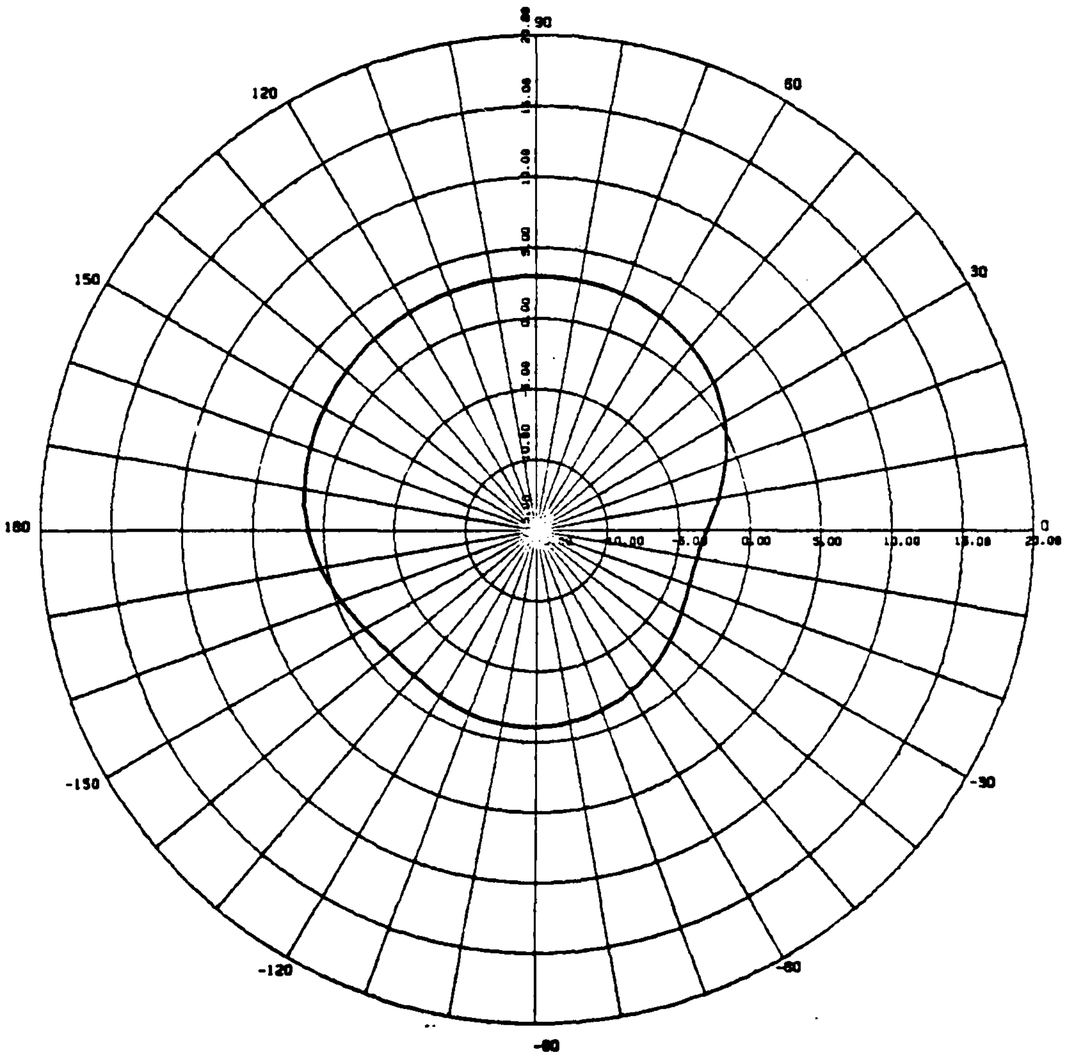
MAC-109 / PHI / THETA=80

WET GRND / JEEP & TRLR / 50 MHZ



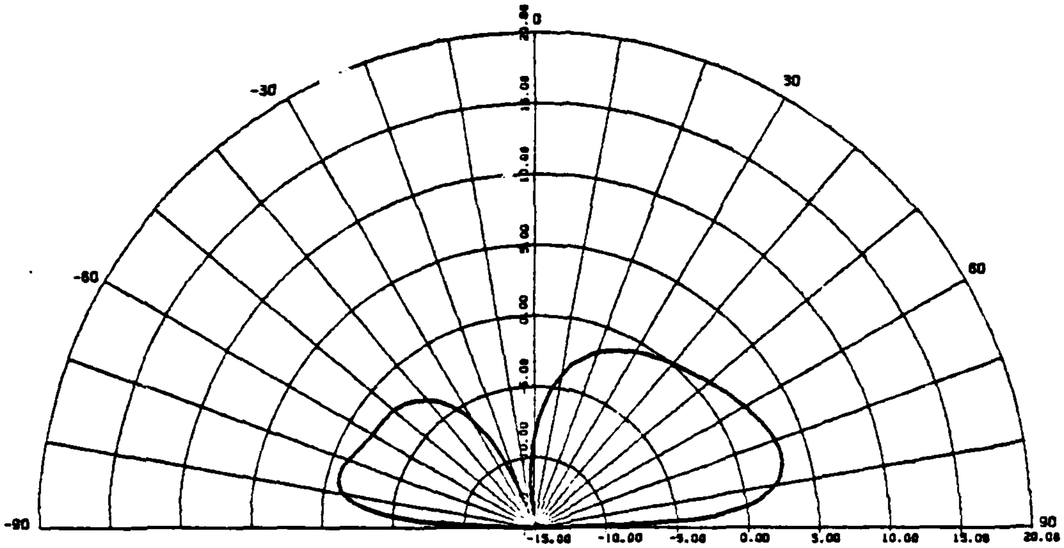
MAC-109 / PHI / THETA=70

WET GRND / JEEP & TALA / 50 MHZ



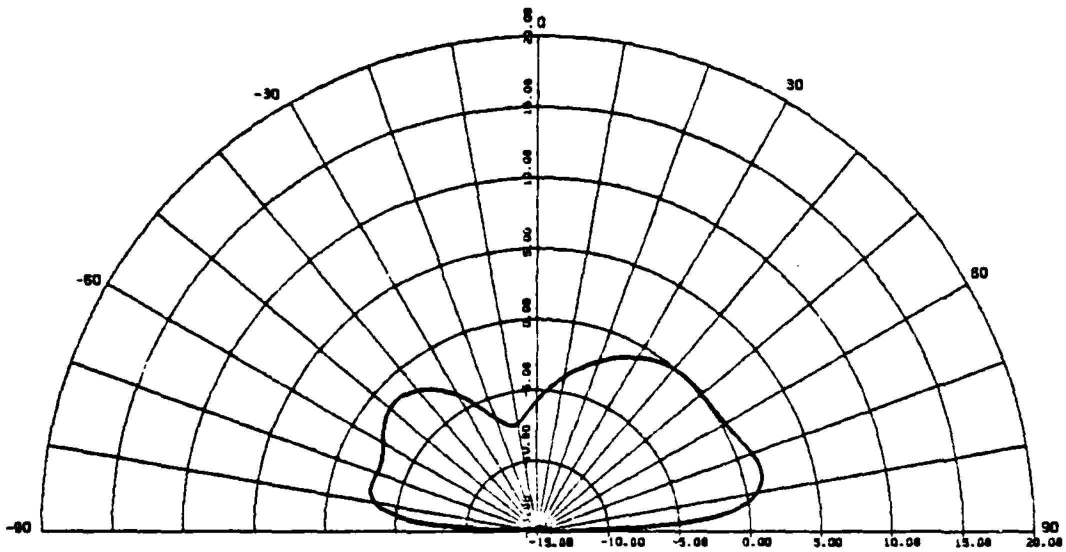
MAC-109 / THETA / PHI=90

WET GRND / JEEP & TALA / 50 MHZ



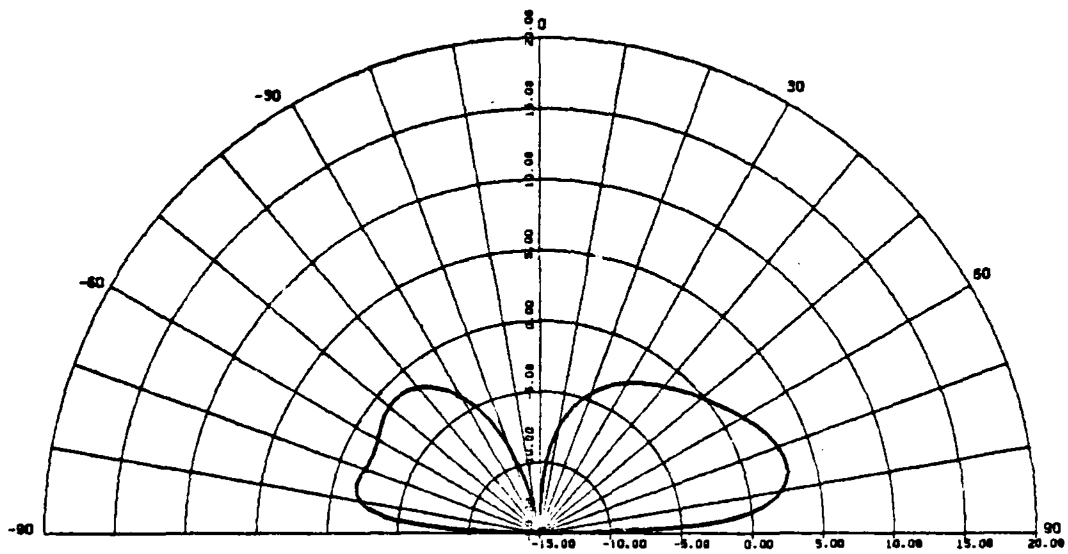
MRC-109 / THETA / PHI=180

WET GRND / JEEP & TRLA / 50 MHZ



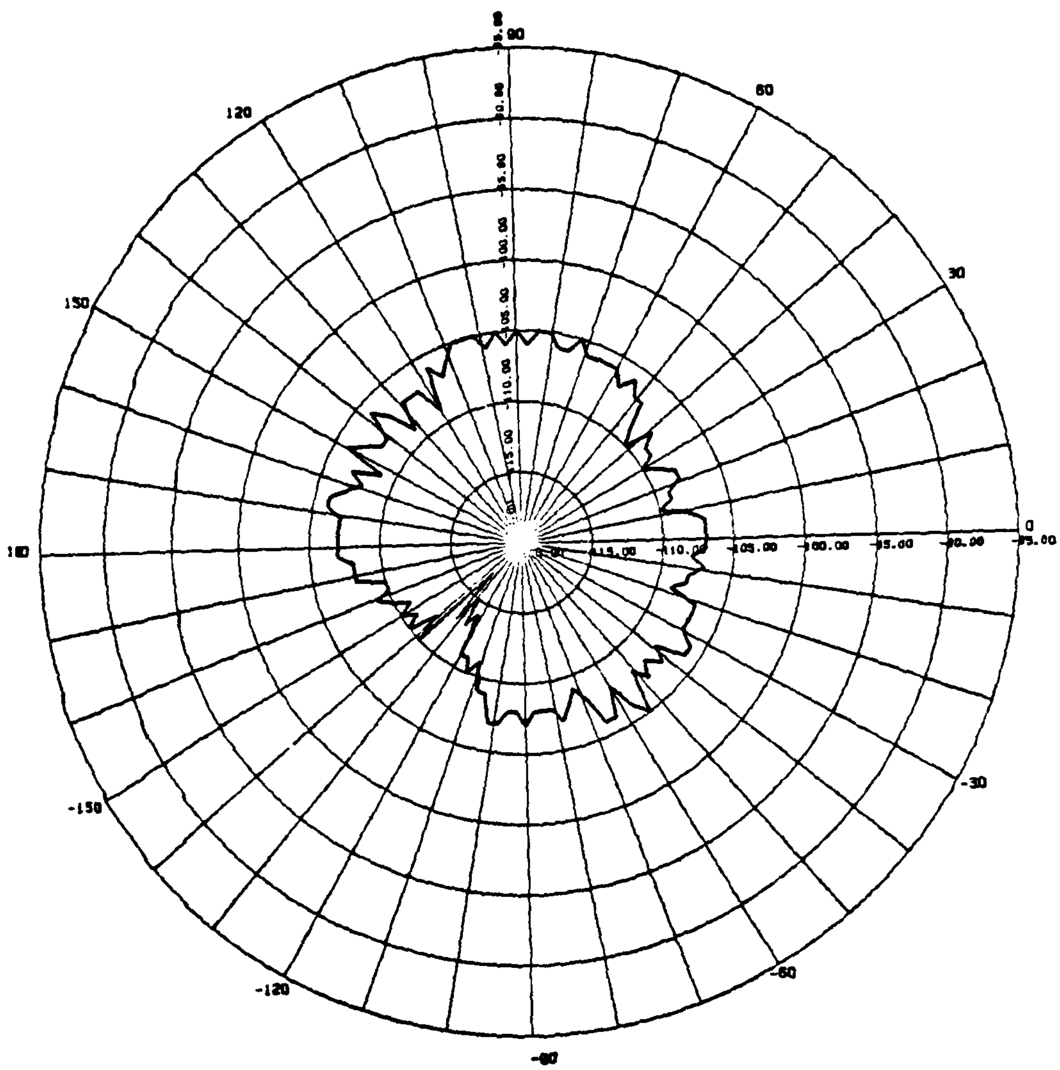
MAC-109 / THETA / PHI=120

WET GAND / JEEP & TRLR / 50 MHZ



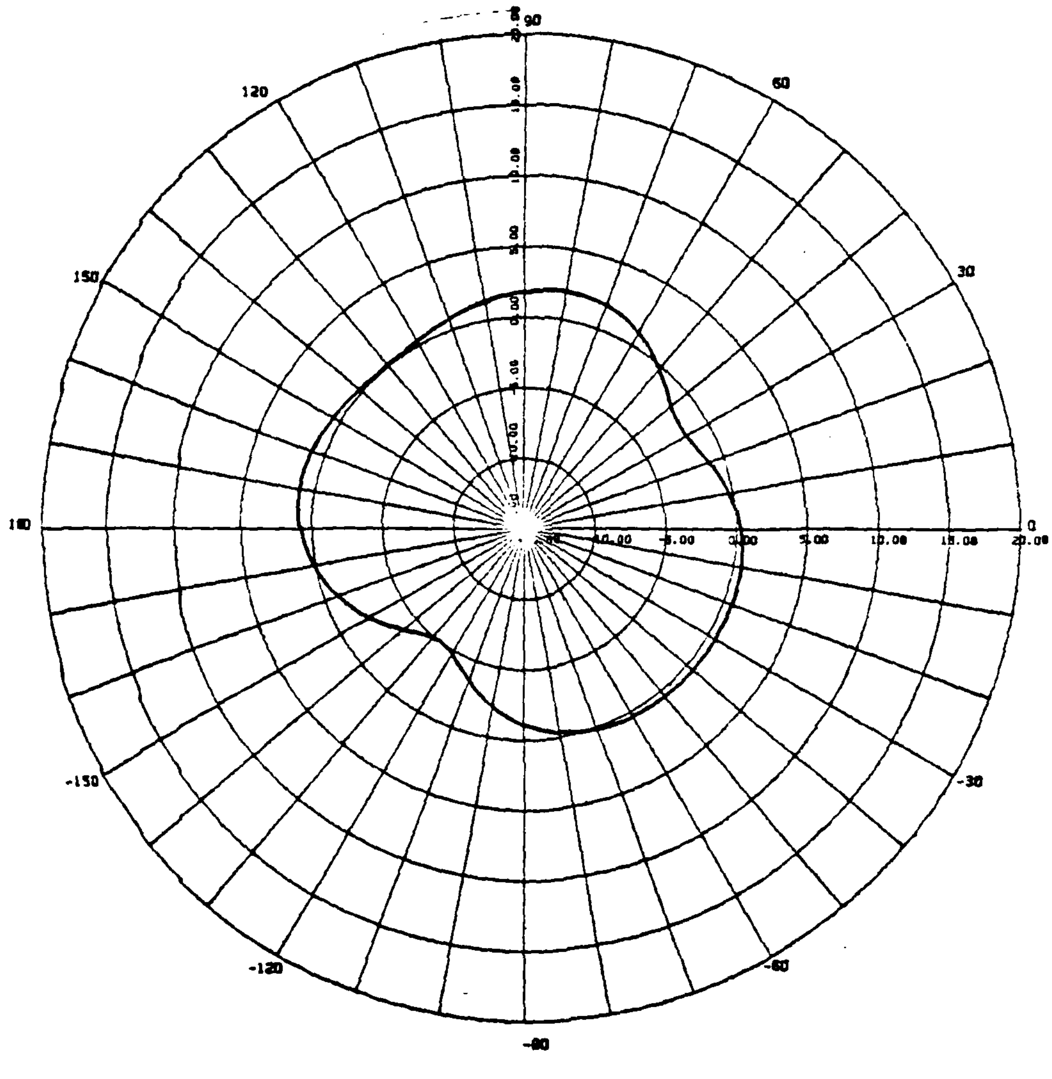
MRC-109 / PHI / THETA=90

WET GRND / JEEP & TALA / 75 MHZ



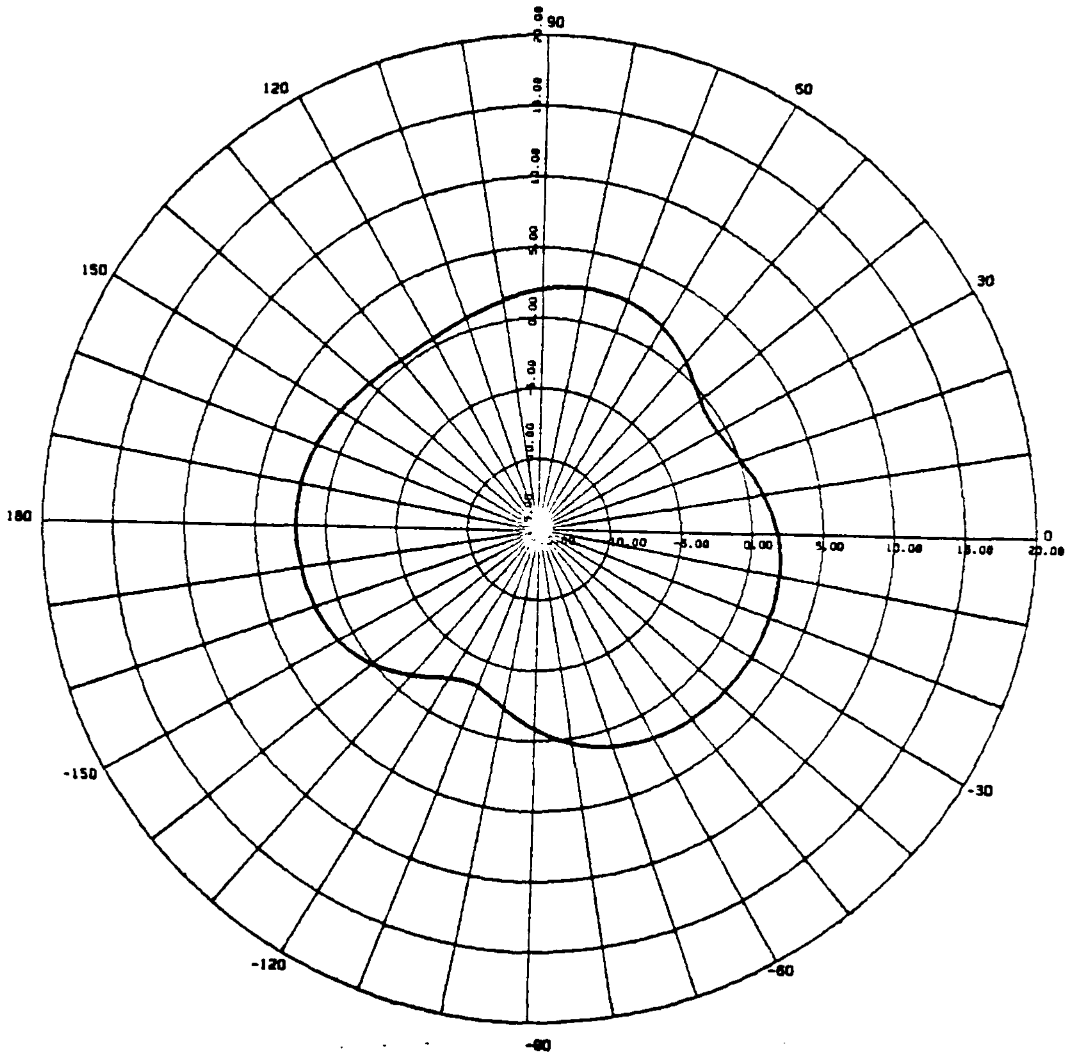
MAC-109 / PHI / THETA=80

WET GRND / JEEP & TALA / 75 MHZ



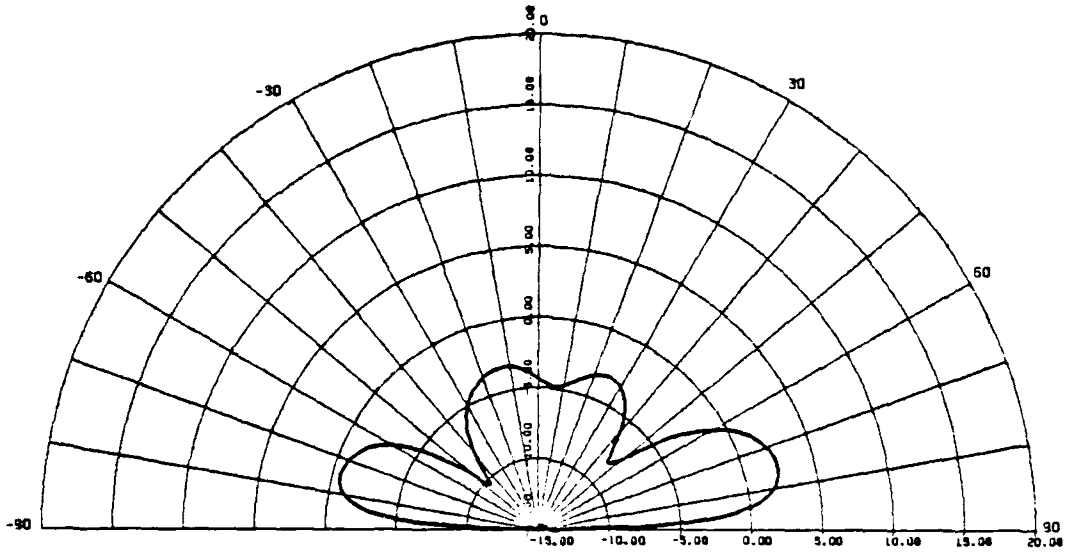
MAC-109 / PHI / THETA=70

WET GRND / JEEP & TALA / 75 MHZ



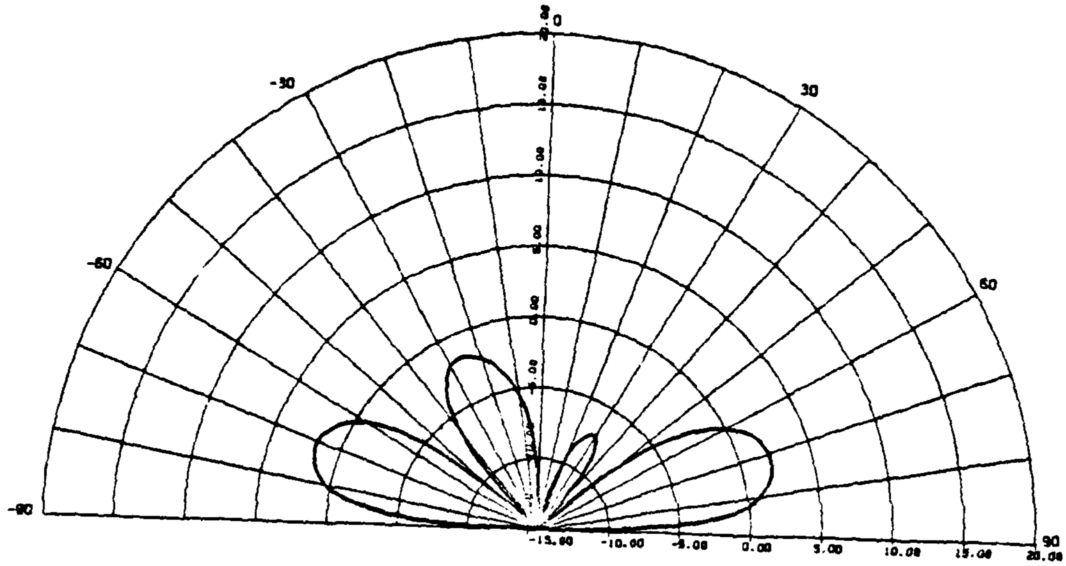
MAC-109 / THETA / PHI=90

WET GRND / JEEP & TRLR / 75 MHZ



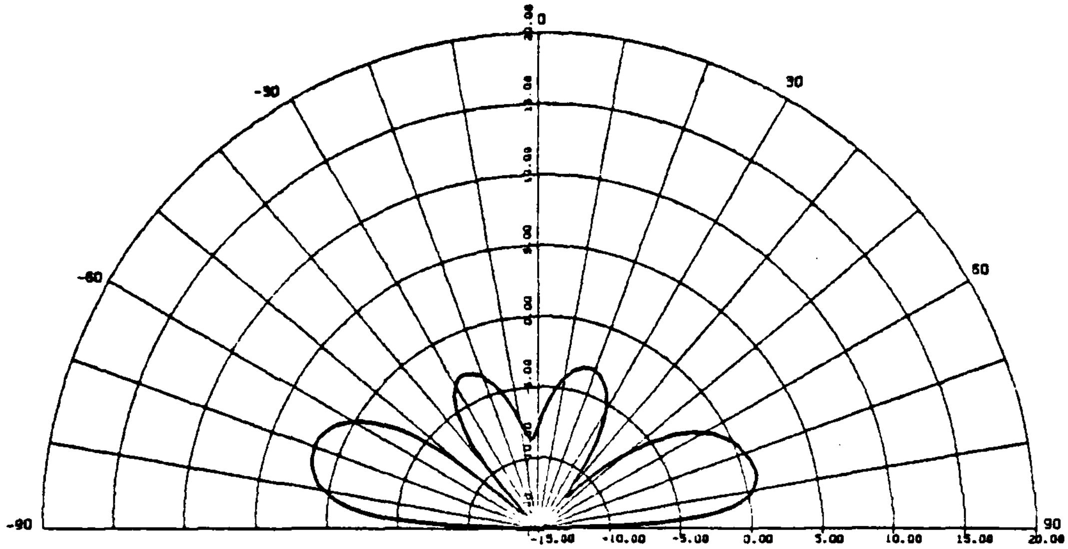
MRC-109 / THETA / PHI=180

WET GRND / JEEP & TRLR / 75 MHZ



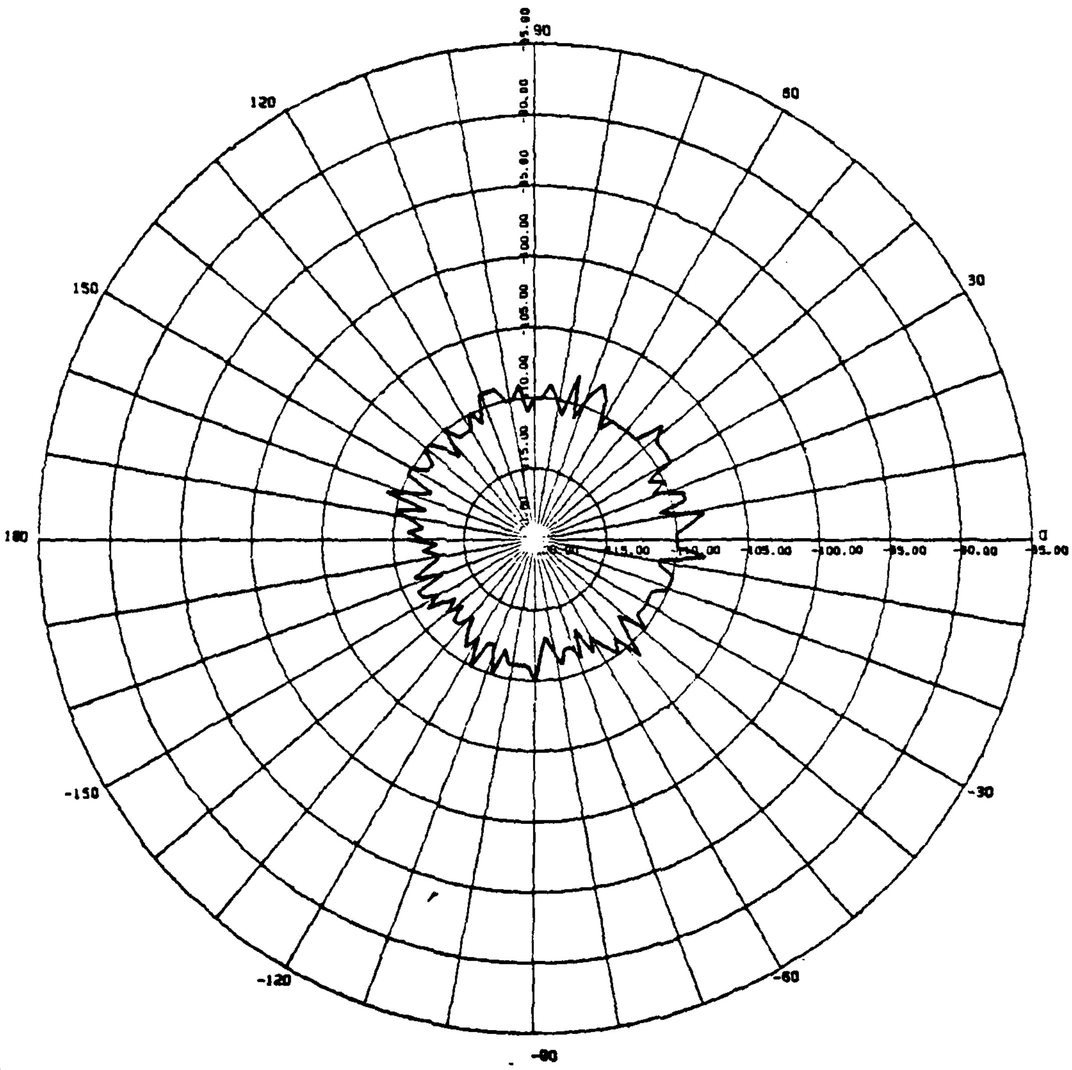
MRC-109 / THETA / PHI=120

WET GRND / JEEP & TRLR / 75 MHZ



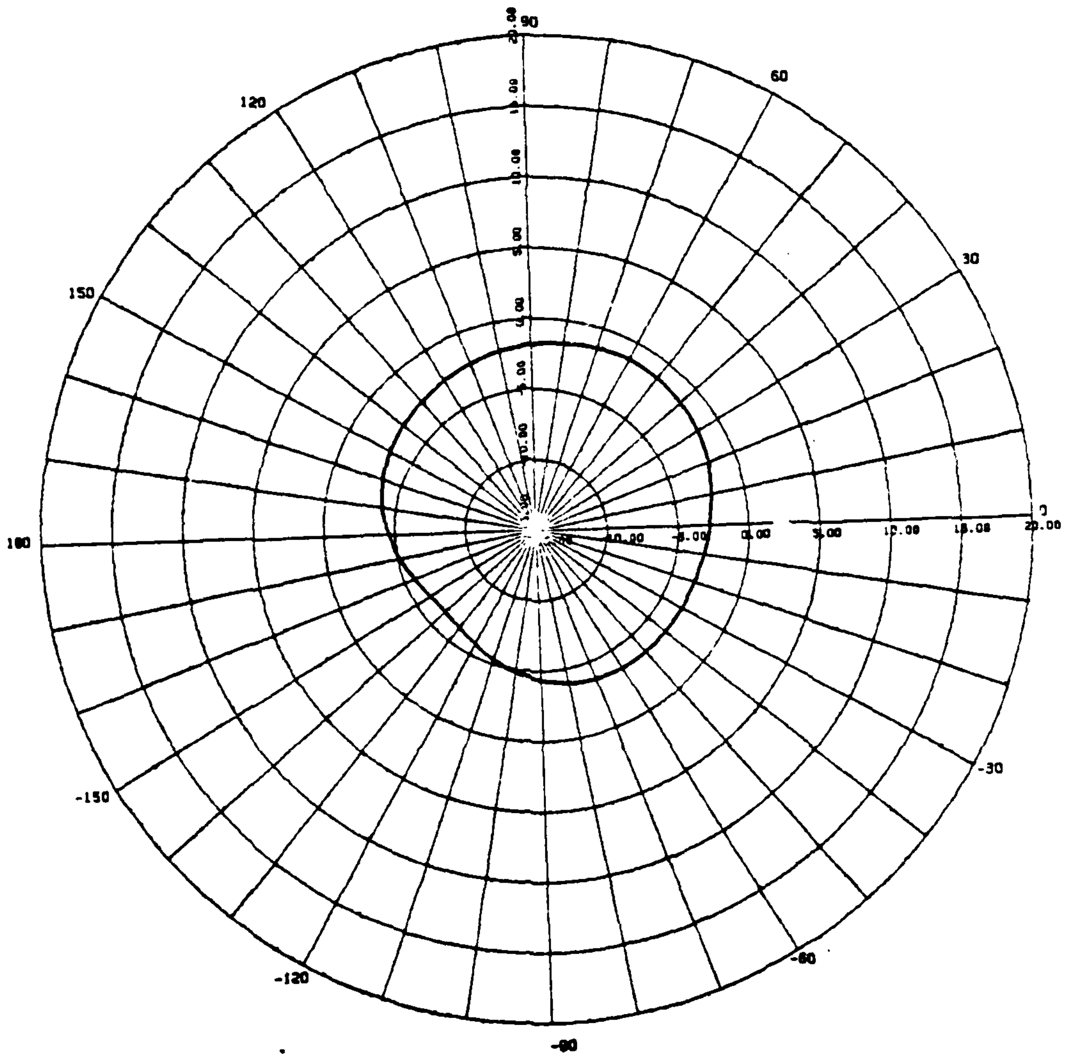
MAC-109 / PHI / THETA=90

PASTORAL / BASIC / 30 MHZ



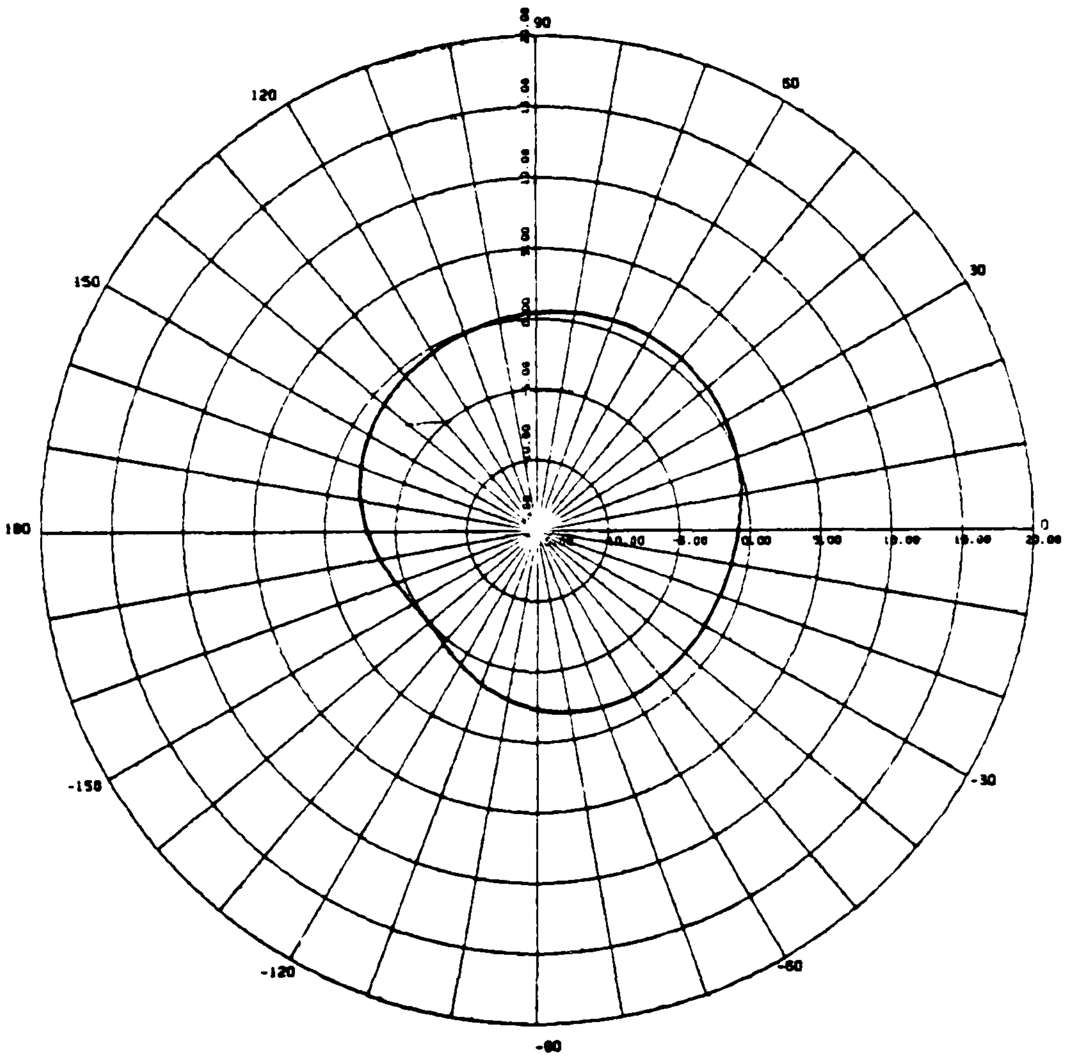
MAC-109 / PHI / THETA= 80

PASTORAL / BASIC / 30 MHZ



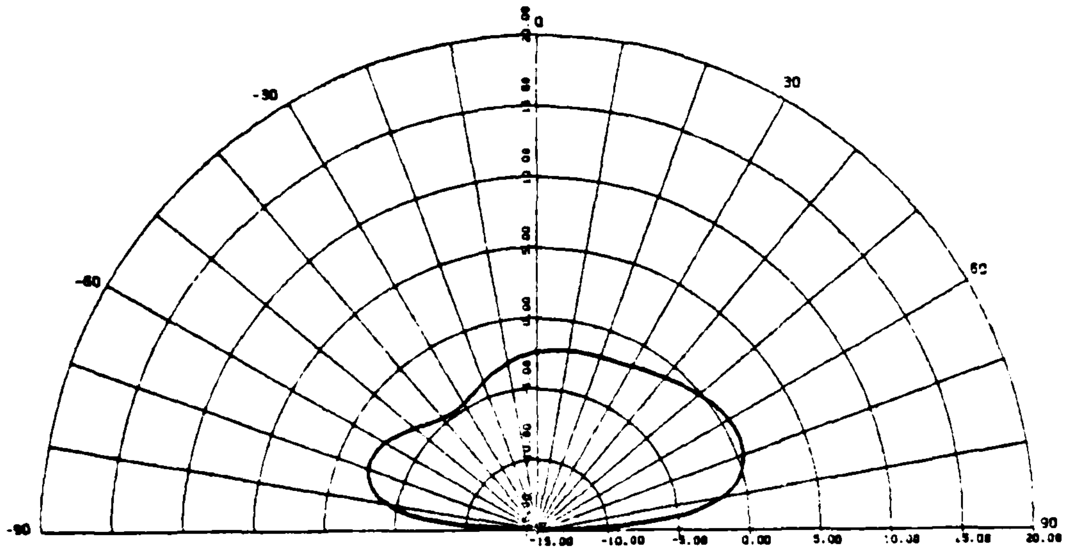
MAC-109 / PHI / THETA= 70

PASTORAL / BASIC / 30 MHZ



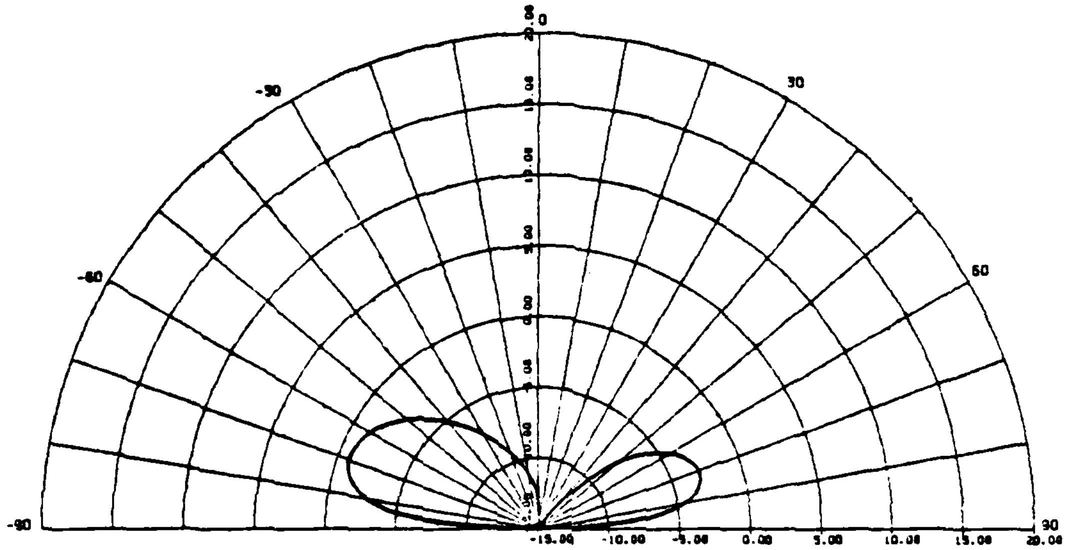
MAC-109 / THETA / PHI = 90

PASTORAL / BASIC / 30 MHZ



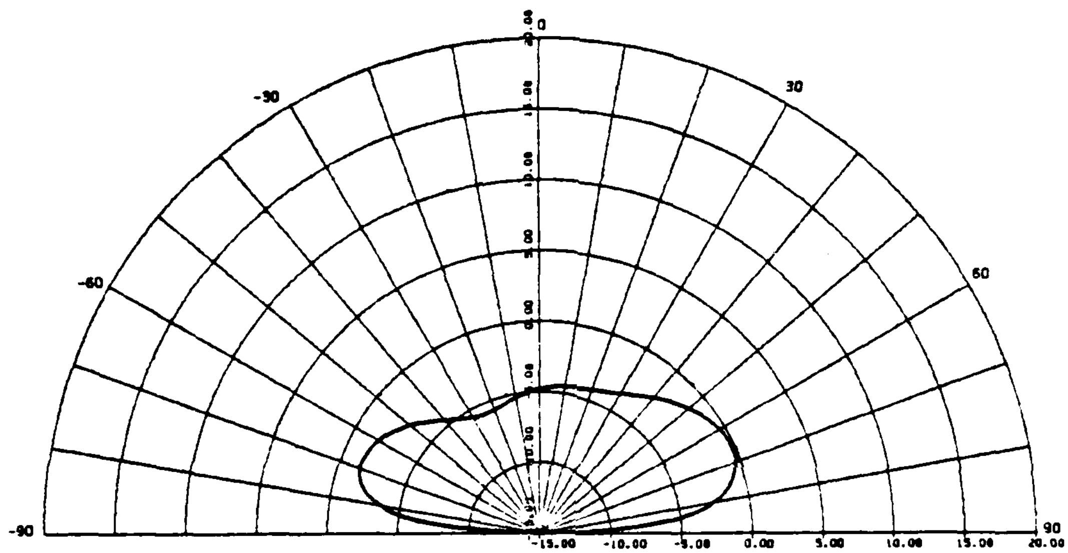
MAC-109 / THETA / PHI = 180

PASTORAL / BASIC / 30 MHZ



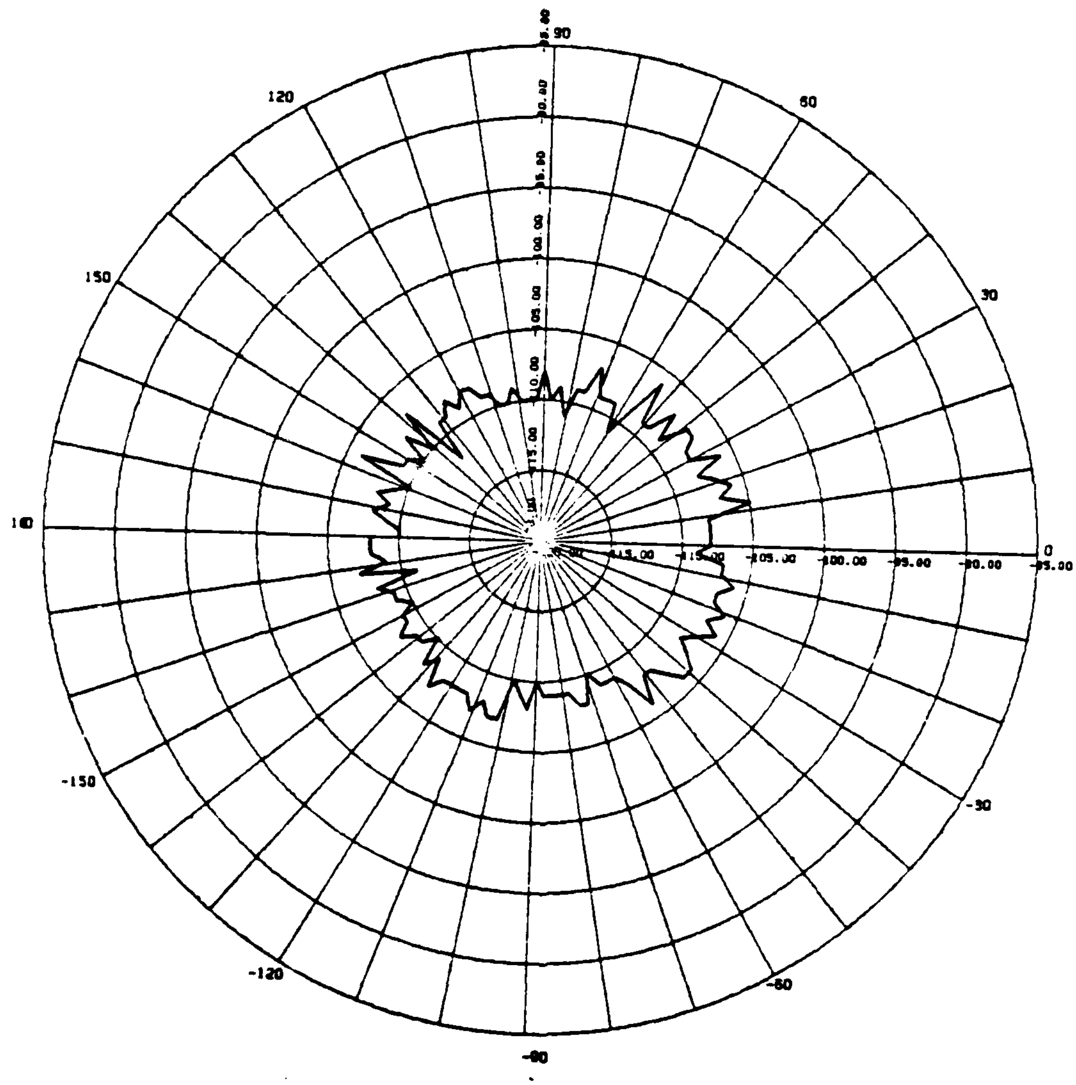
MAC-109 / THETA / PHI = 120

PASTORAL / BASIC / 30 MHZ



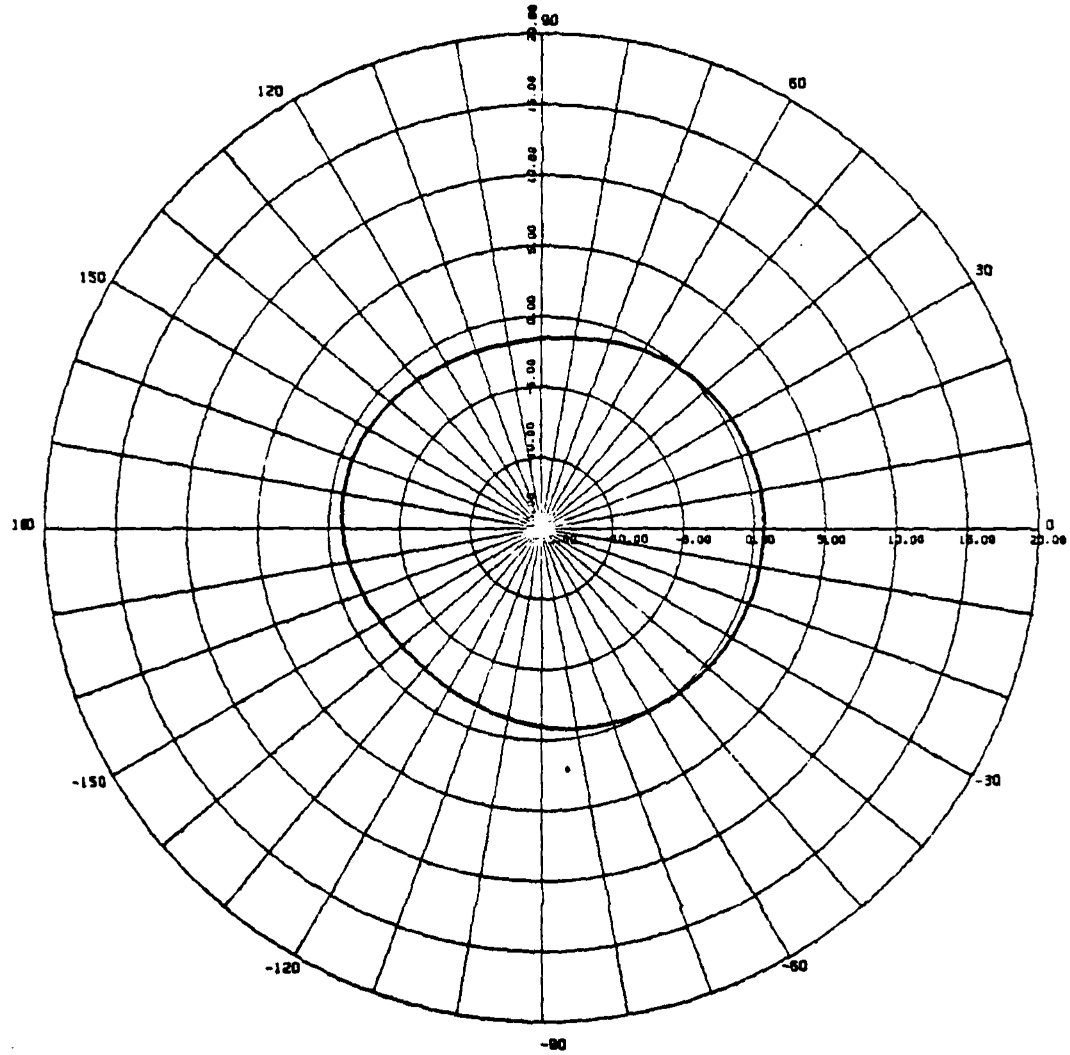
MAC-109 / PHI / THETA=90

PASTORAL / BASIC / 41 MHZ



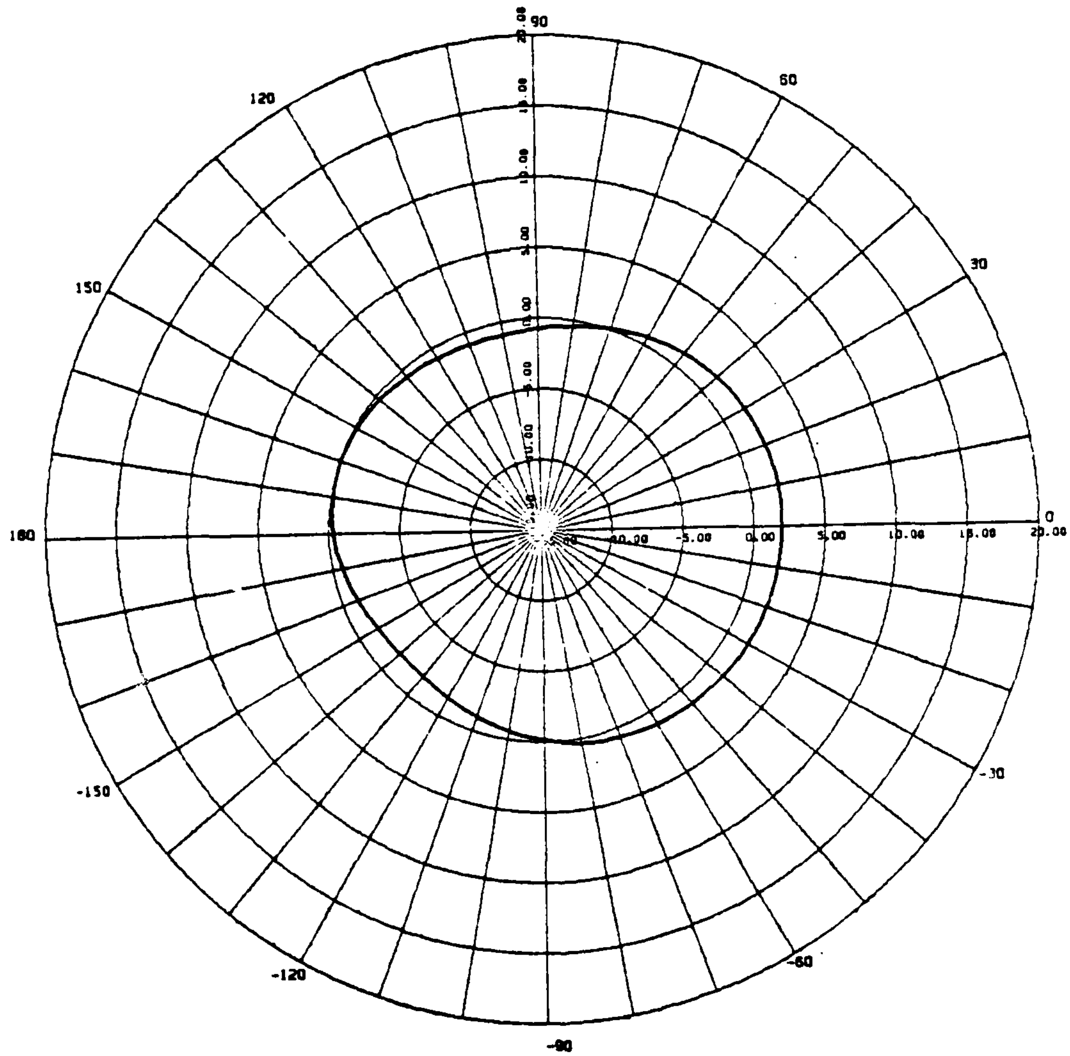
MAC-109 / PHI / THETA= 80

PASTORAL / BASIC / 41 MHZ



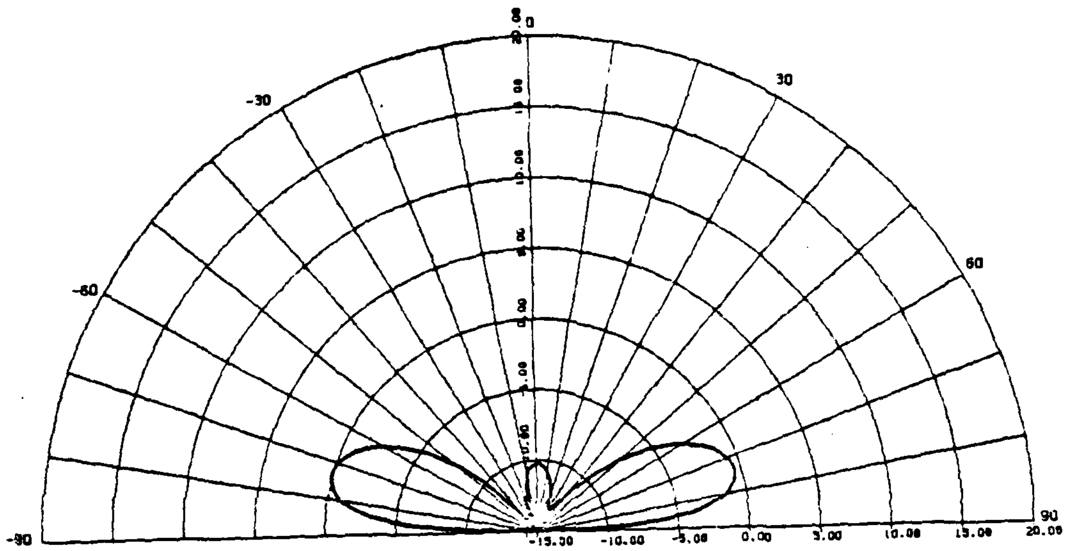
MRC-109 / PHI / THETA= 70

PASTORAL / BASIC / 41 MHZ



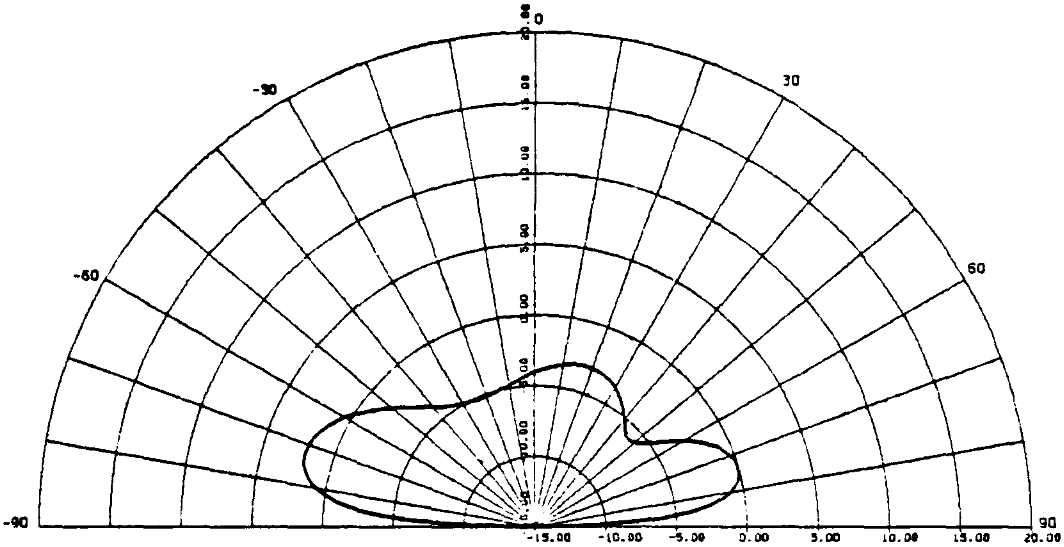
MAC-109 / THETA / PHI = 90

PASTORAL / BASIC / 41 MHZ



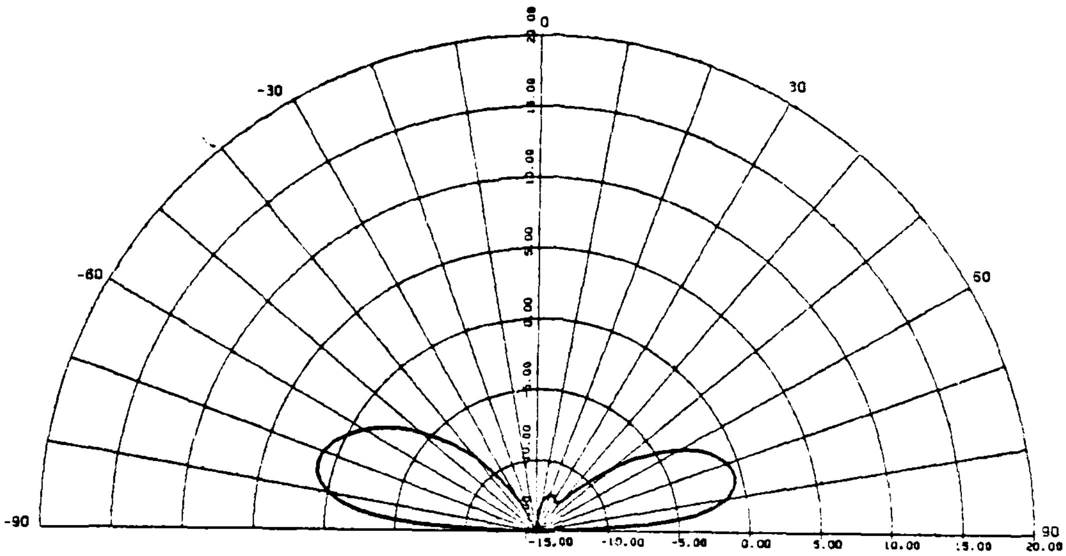
MRC-109 / THETA / PHI = 180

PASTORAL / BASIC / 41 MHZ



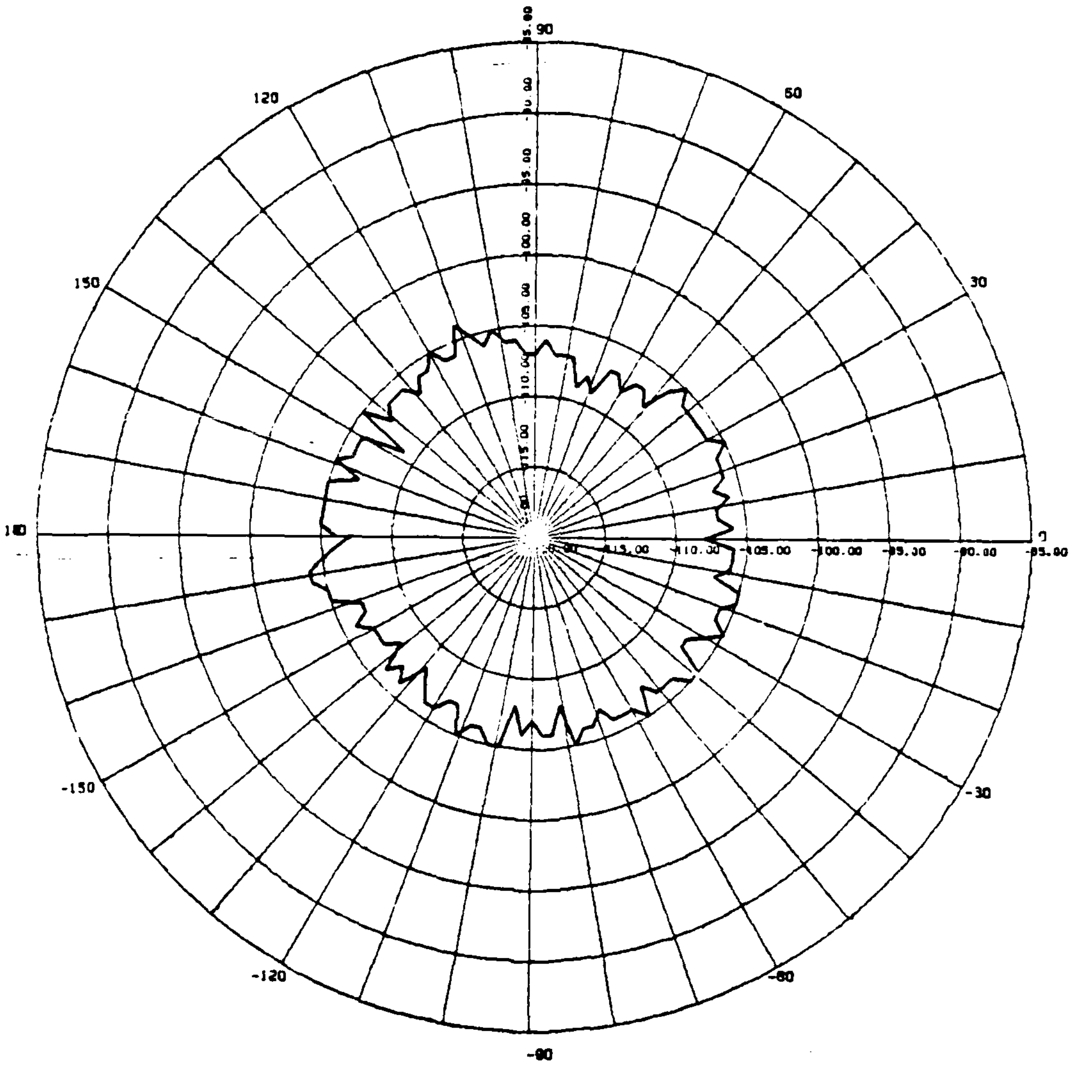
MAC-103 / THETA / PHI = 120

PASTORAL / BASIC / 41 MHZ



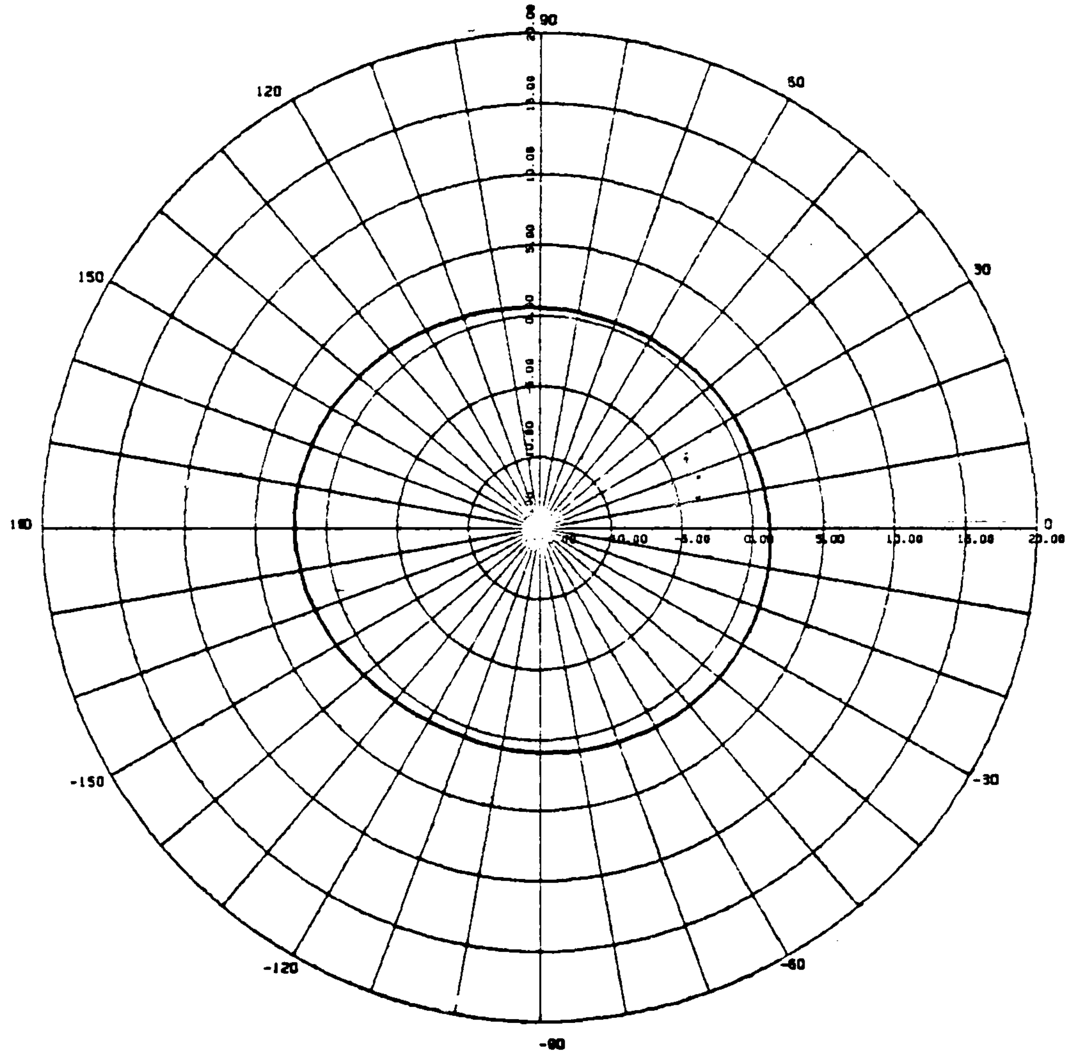
MAC-109 / PHI / THETA=90

PASTORAL / BASIC / 50 MHZ



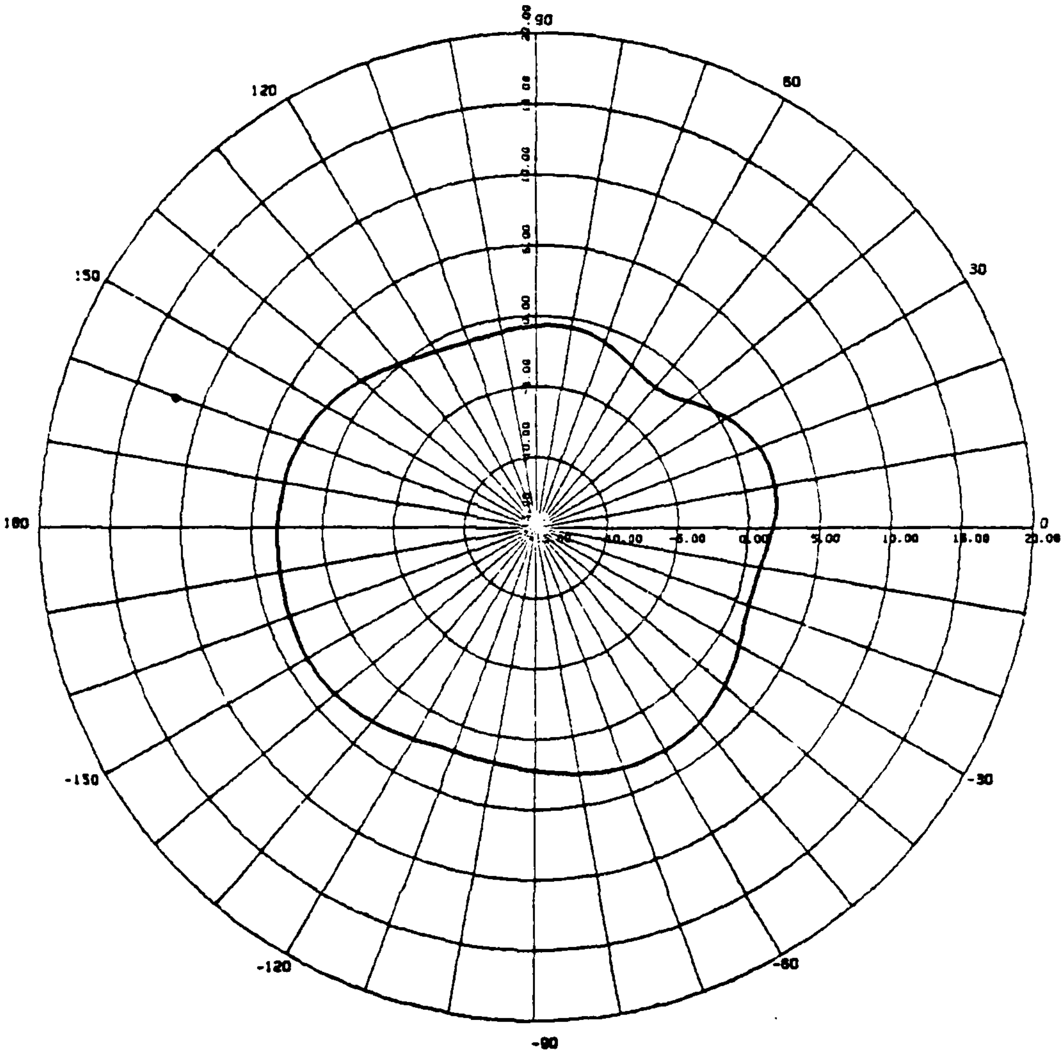
MAC-109 / PHI / THETA= 80

PASTORAL / BASIC / 50 MHZ



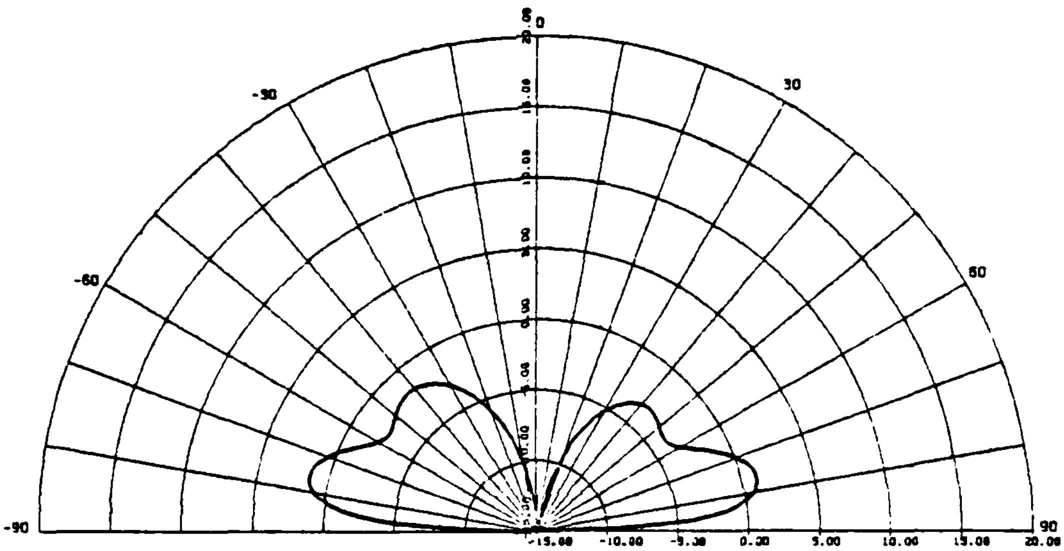
MRC-109 / PHI / THETA= 70

PASTORAL / BASIC / 75 MHZ



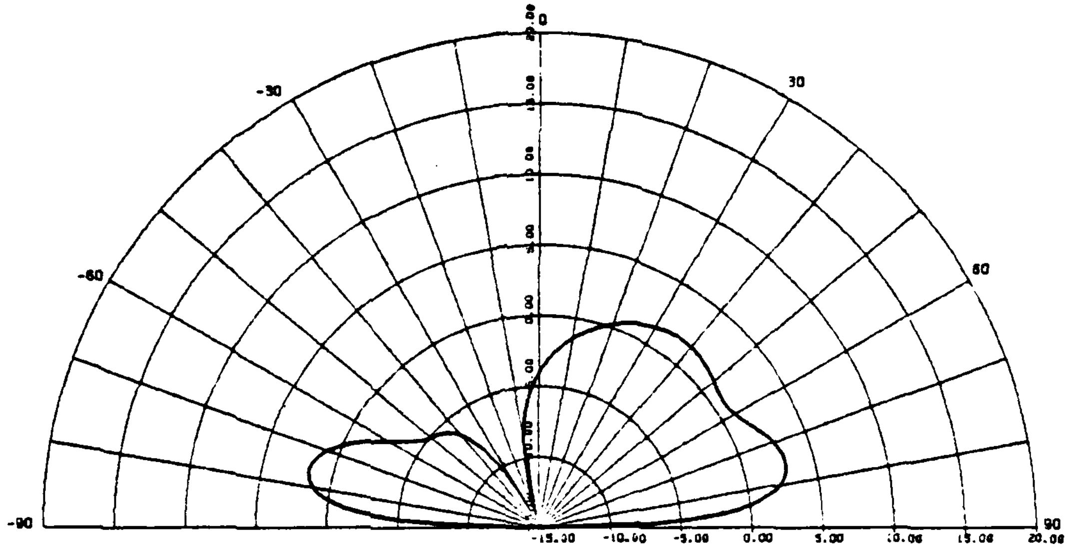
MAC-109 / THETA / PHI = 90

PASTORAL / BASIC / 50 MHZ



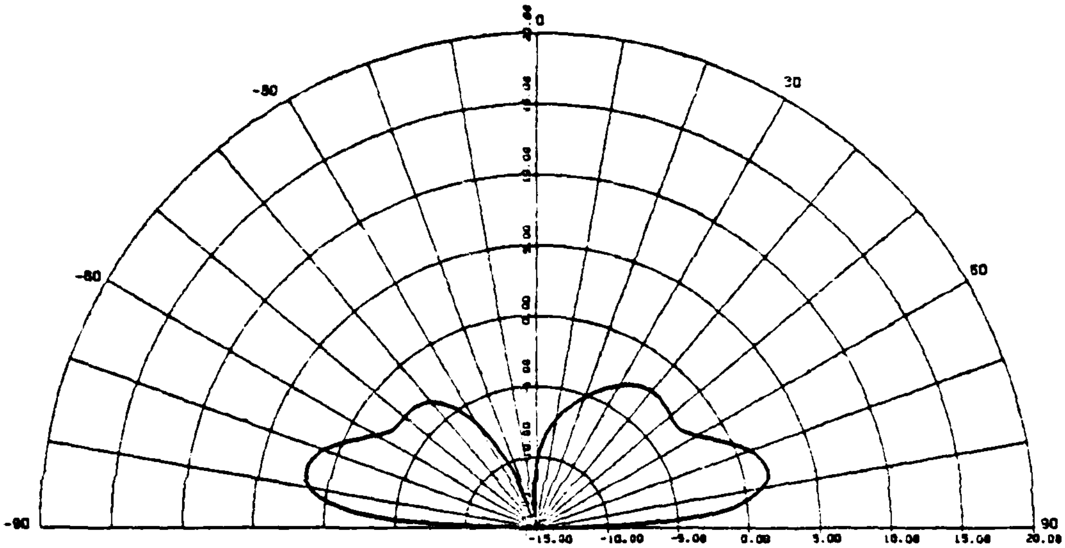
MAC-109 / THETA / PHI = 180

PASTORAL / BASIC / 50 MHZ



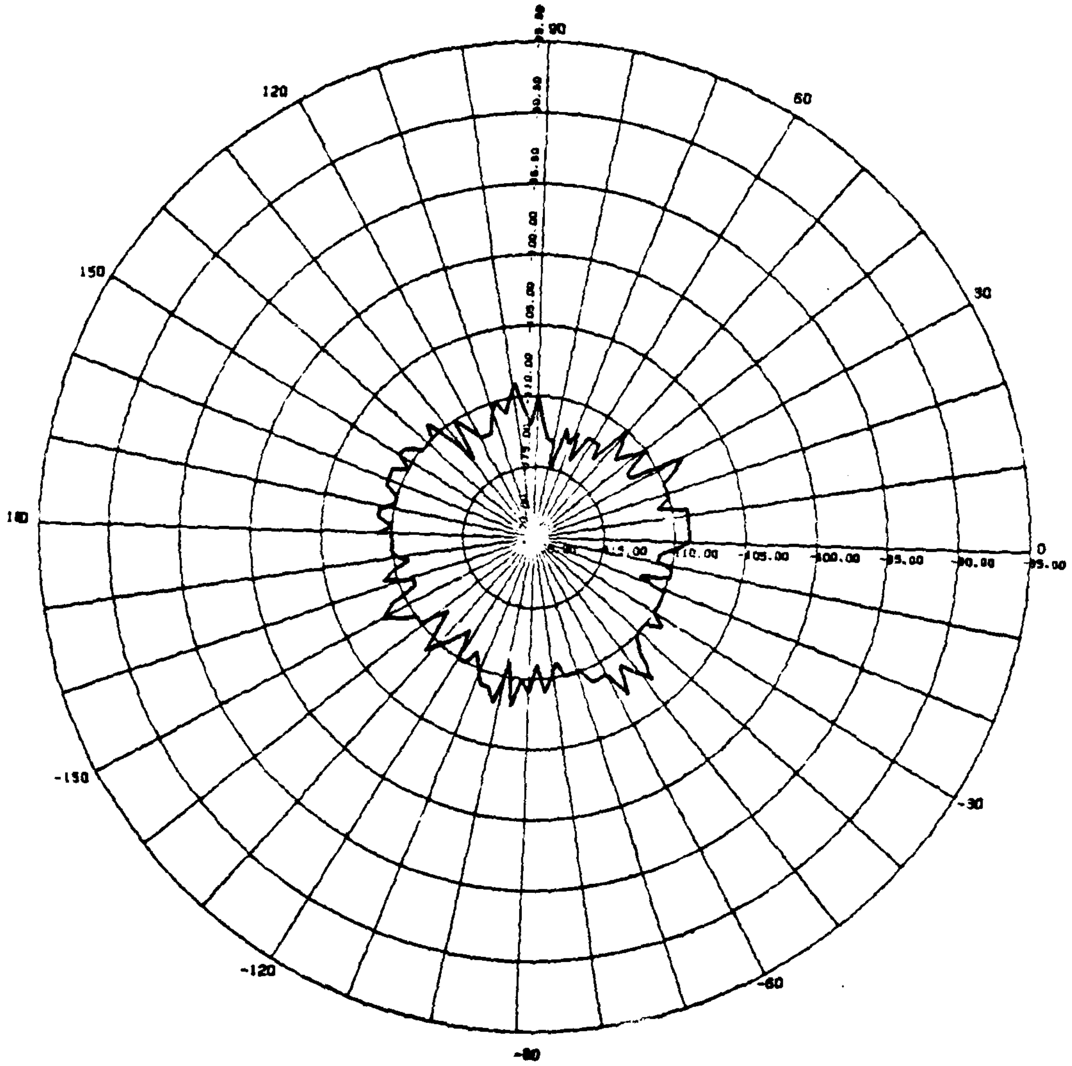
MAC-109 / THETA / PHI = 120

PASTORAL / BASIC / 50 MHZ



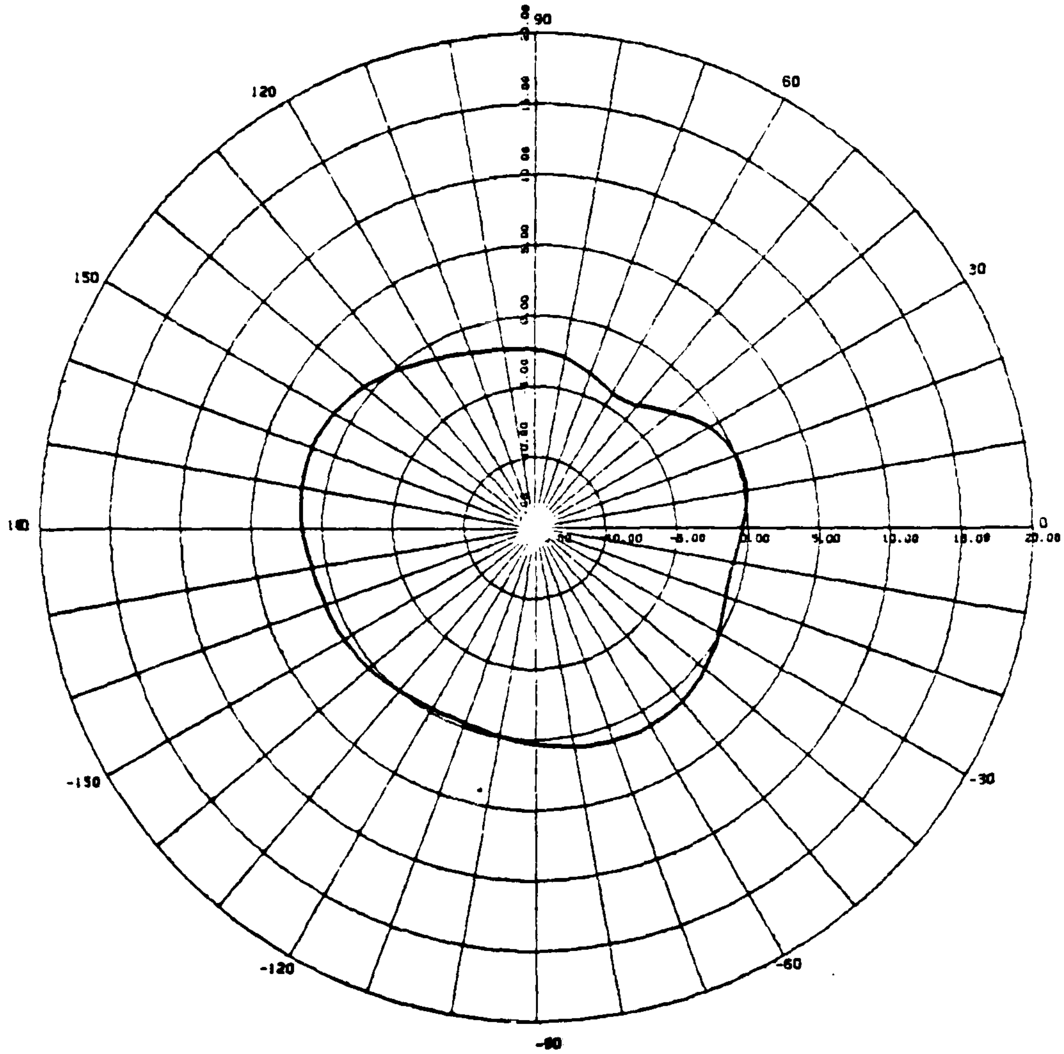
MAC-109 / PHI / THETA=90

PASTORAL / BASIC / 75 MHZ



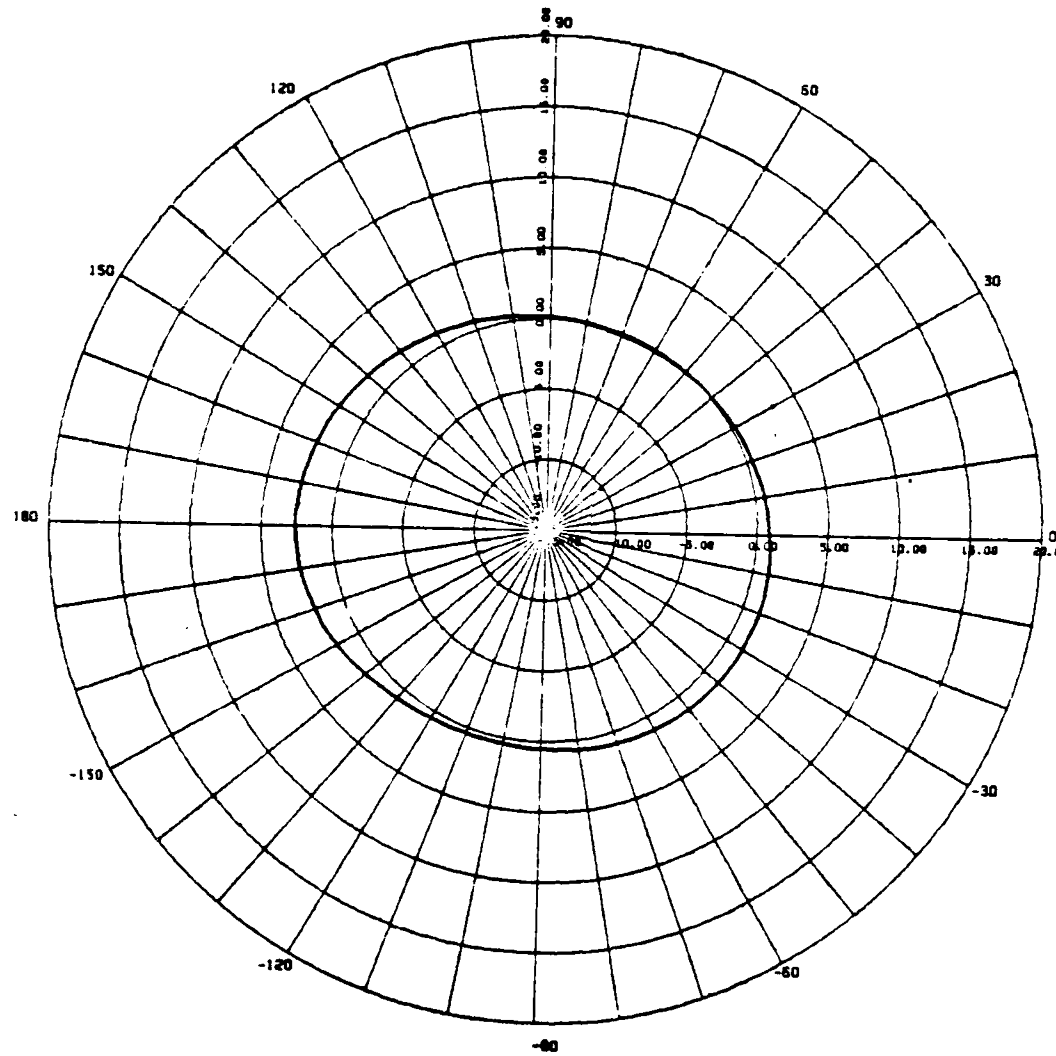
MAC-109 / PHI / THETA= 80

PASTORAL / BASIC / 75 MHZ



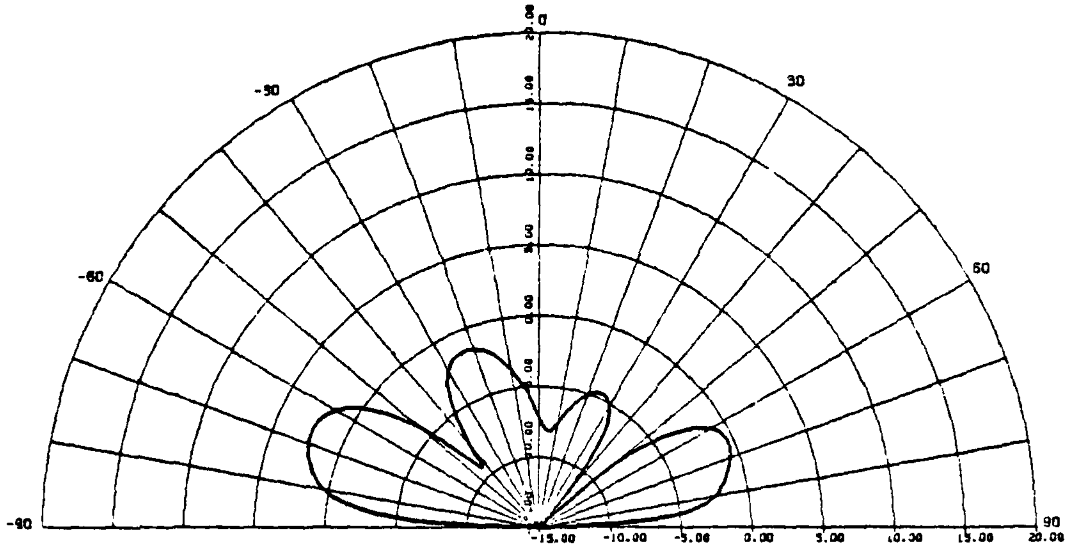
MAC-109 , PHI / THETA= 70

PASTORAL / BASIC / 50 MHZ



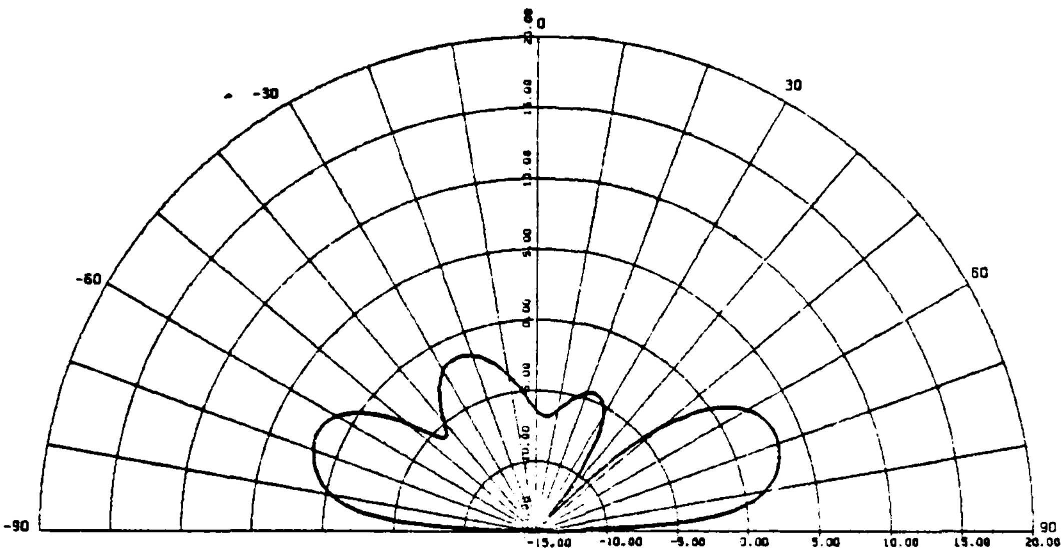
MAC-109 / THETA / PHI = 90

PASTORAL / BASIC / 75 MHZ



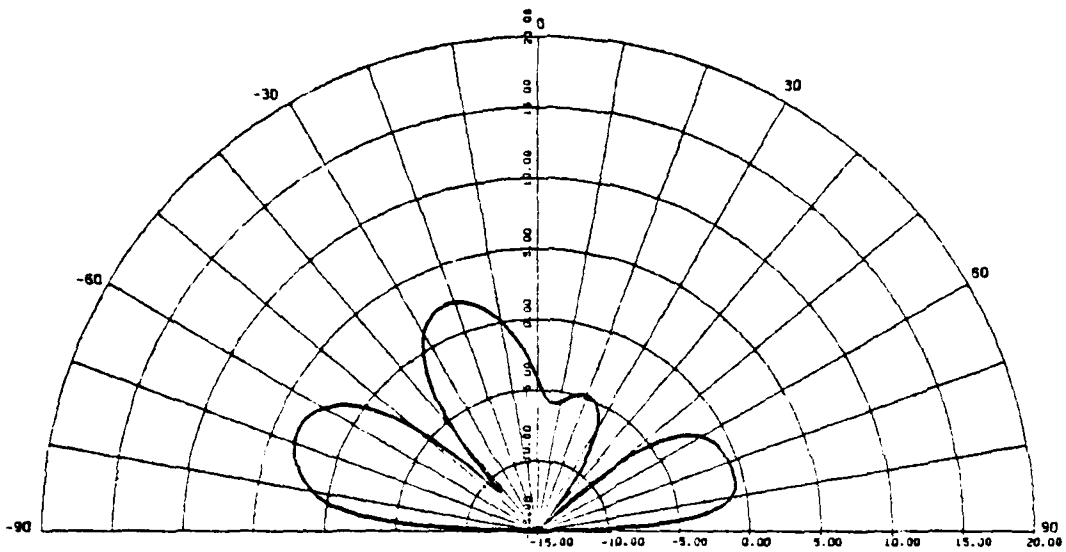
MRC-109 / THETA / PHI = 180

PASTORAL / BASIC / 75 MHZ



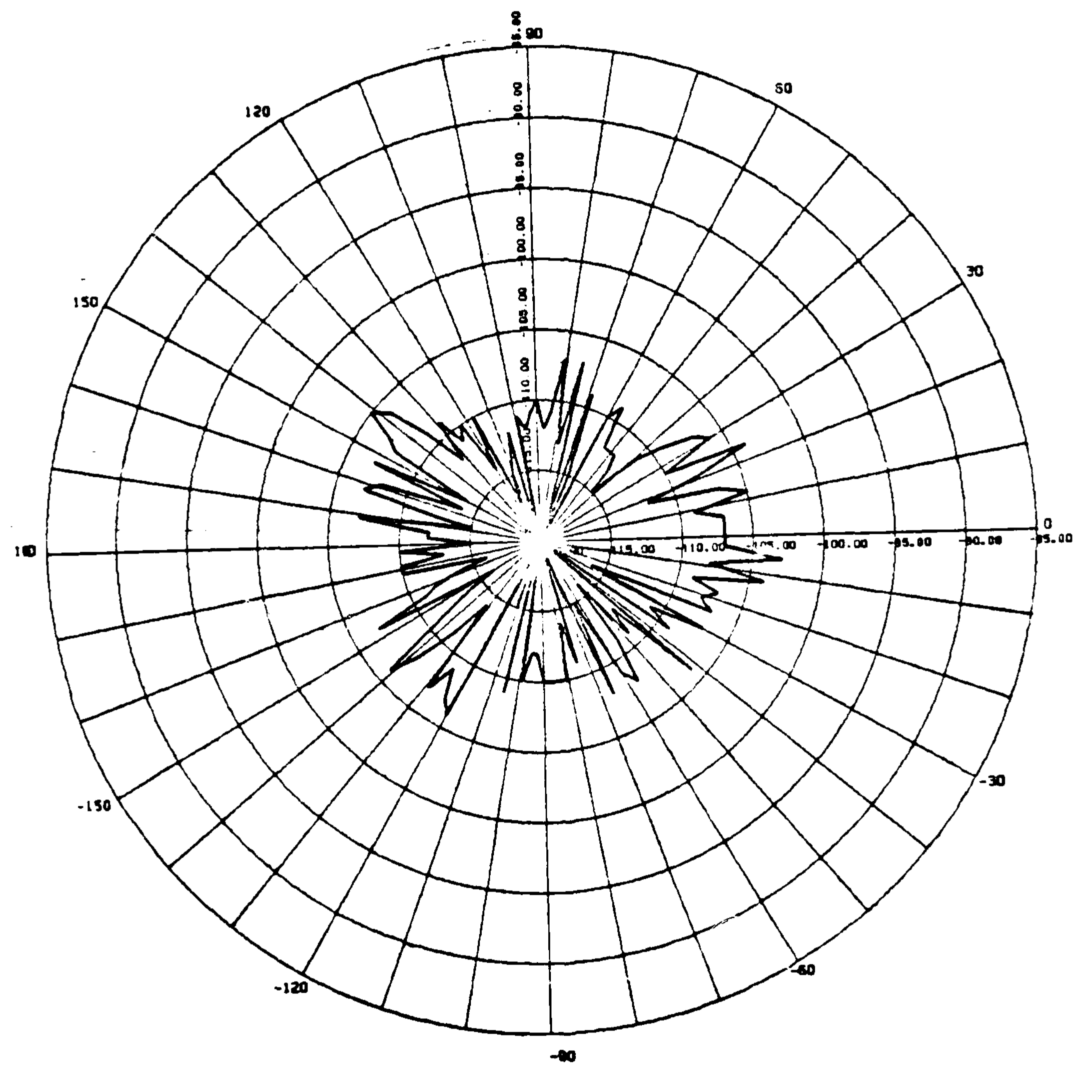
MAC-109 / THETA / PHI = 120

PASTORAL / BASIC / 75 MHZ



MAC-109 / PHI / THETA=90

PASTORAL / JEEP / 30 MHZ



MRC-109 / PHI / THETA= 90

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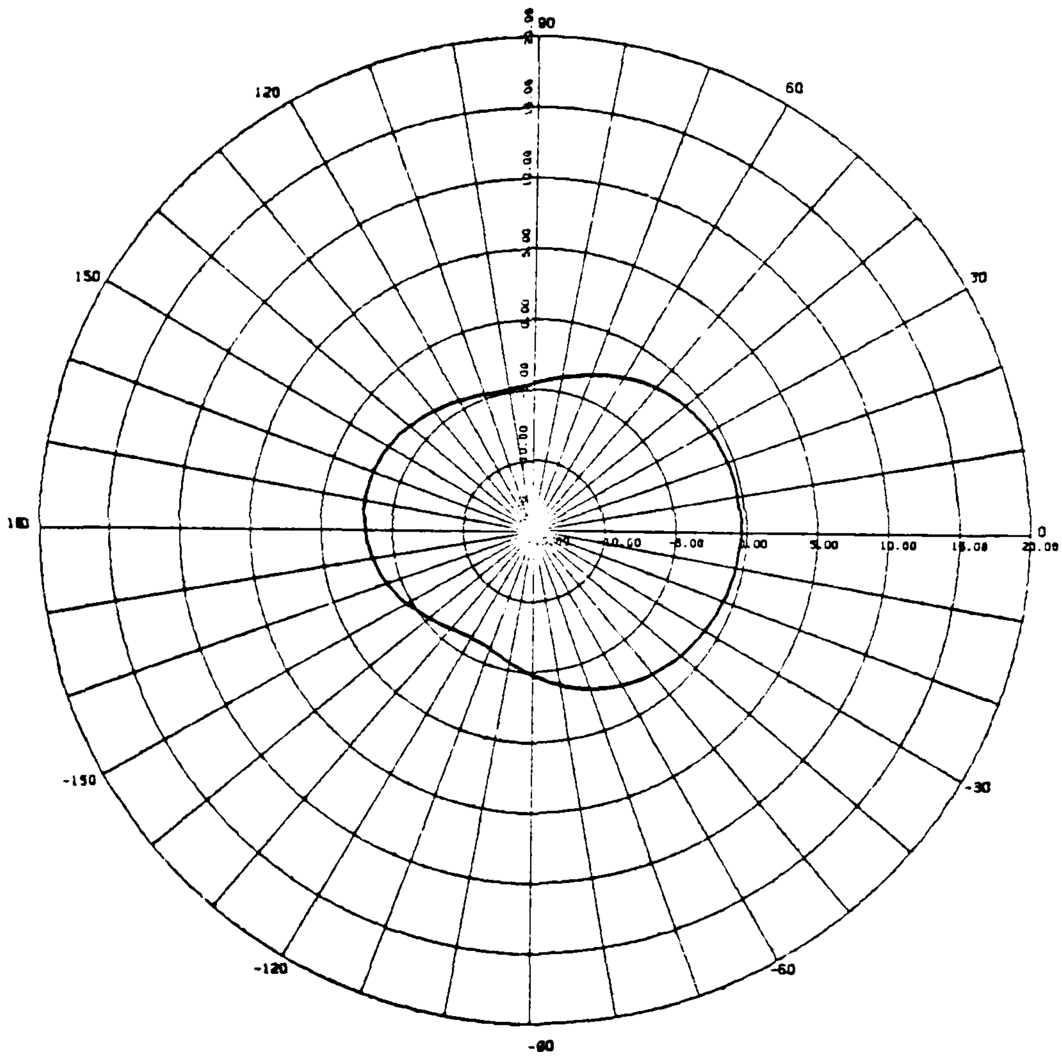
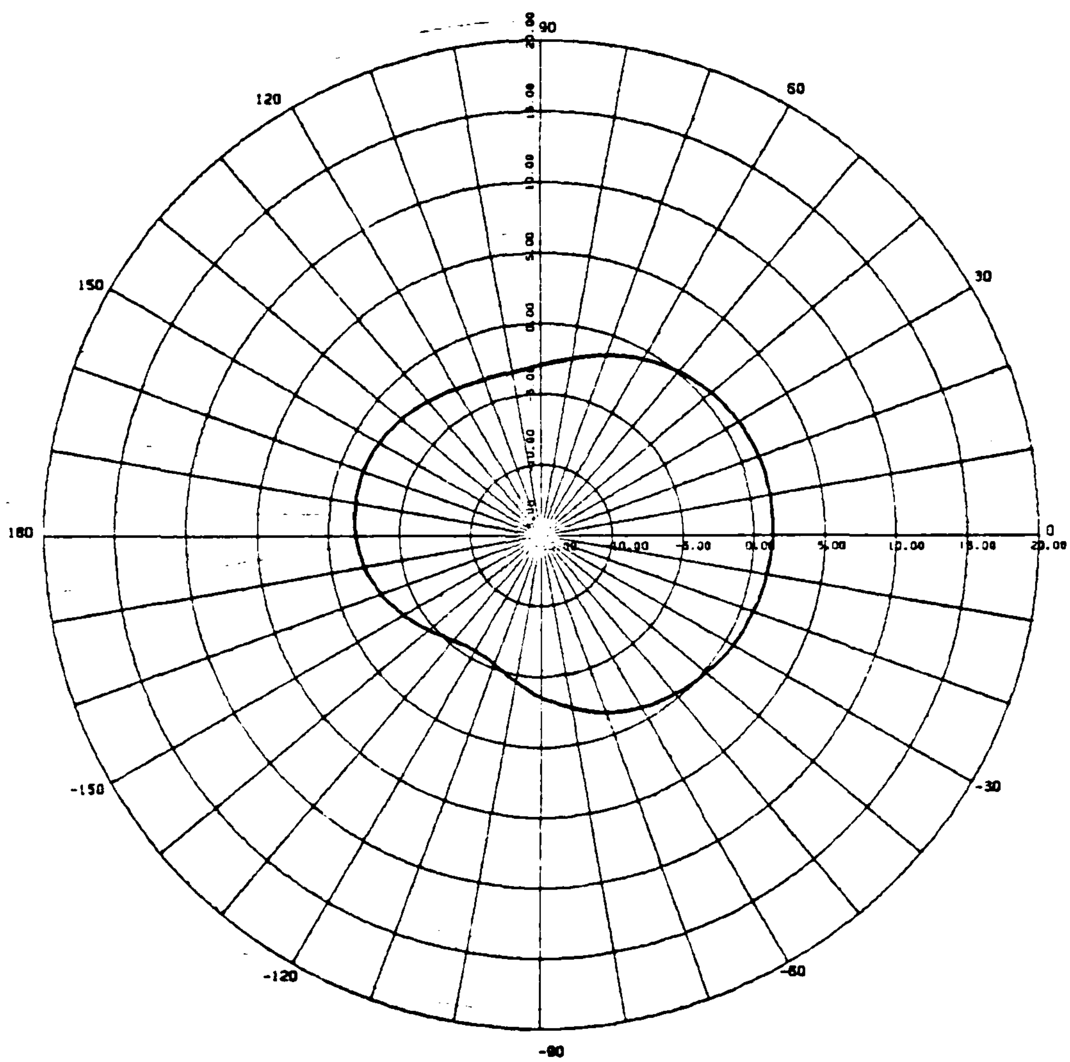


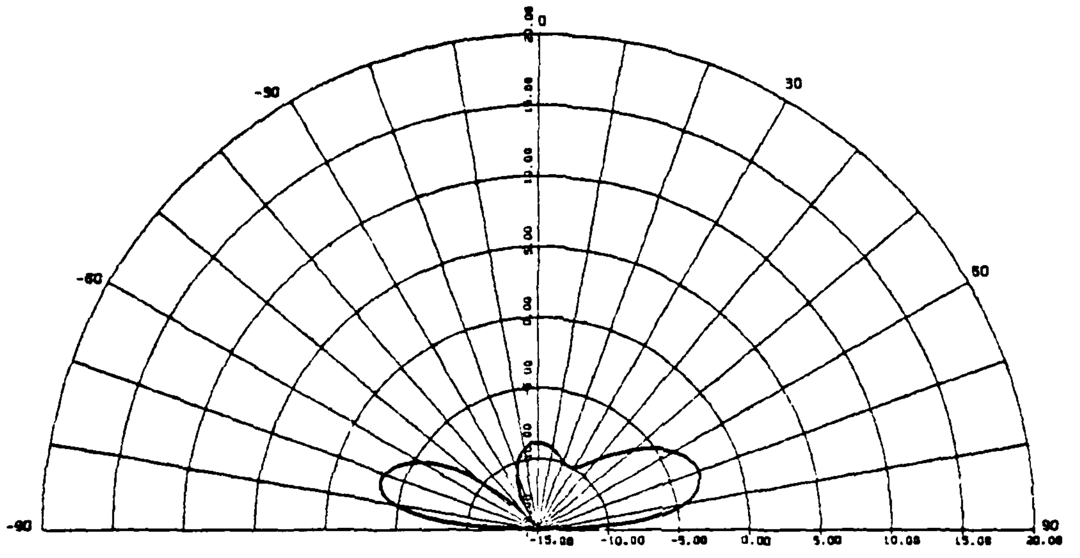
MRC-109 / PHI / THETA= 70

PASTORAL / JEEP / 30 MHZ



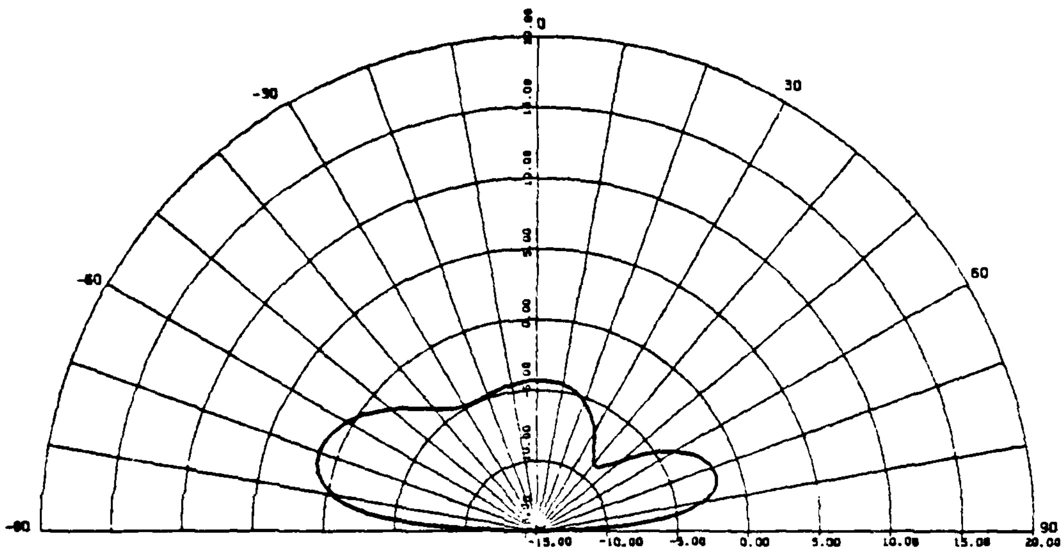
MAC-109 / THETA / PHI = 90

PASTORAL / JEEP / 30 MHZ



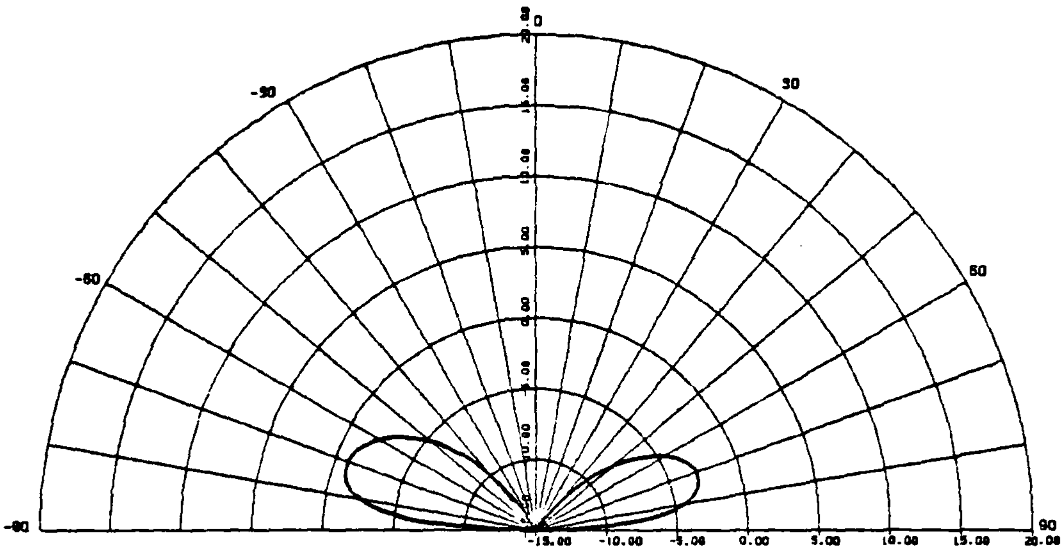
MRC-109 / THETA / PHI = 180

PASTORAL / JEEP / 30 MHZ



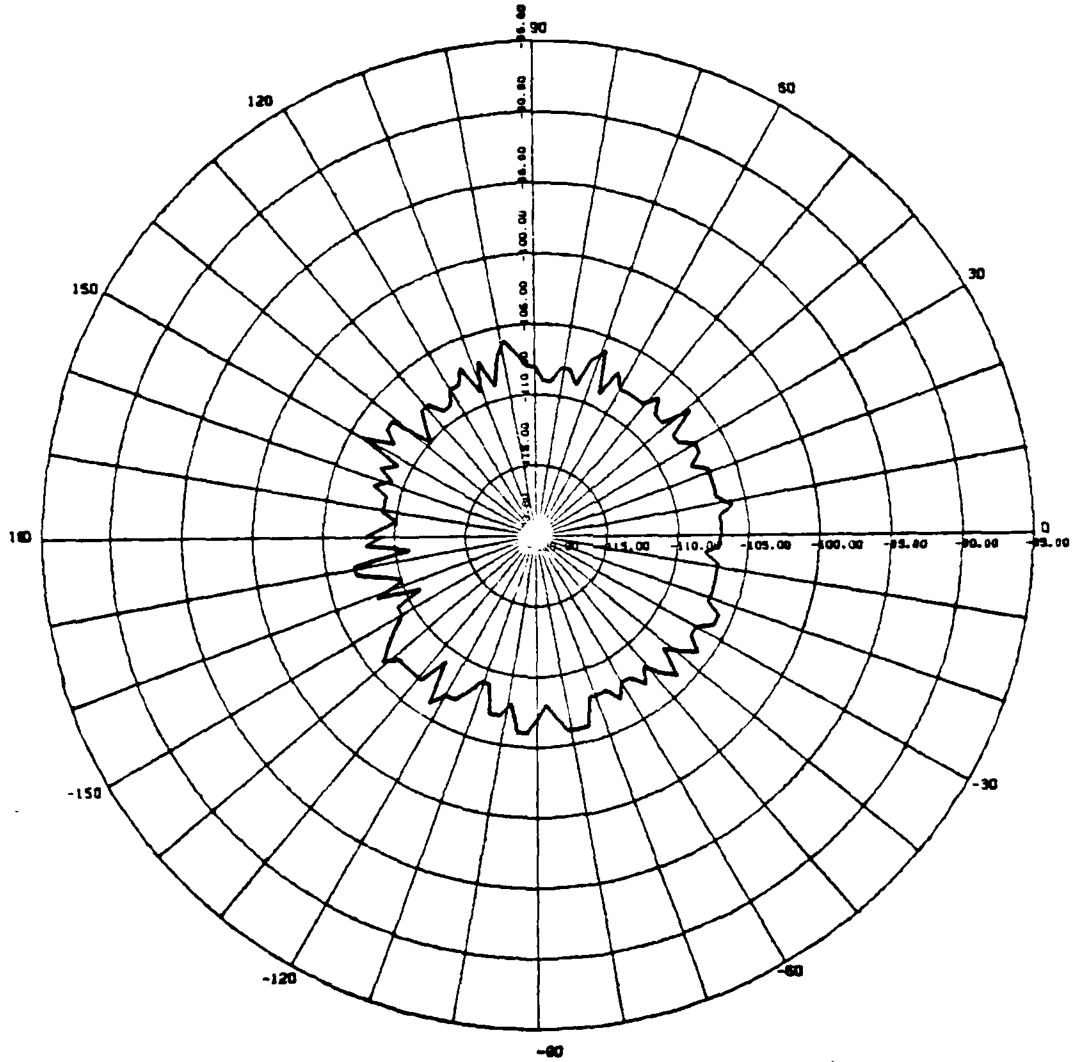
MAC-109 / THETA / PHI = 120

PASTORAL / JEEP / 30 MHZ



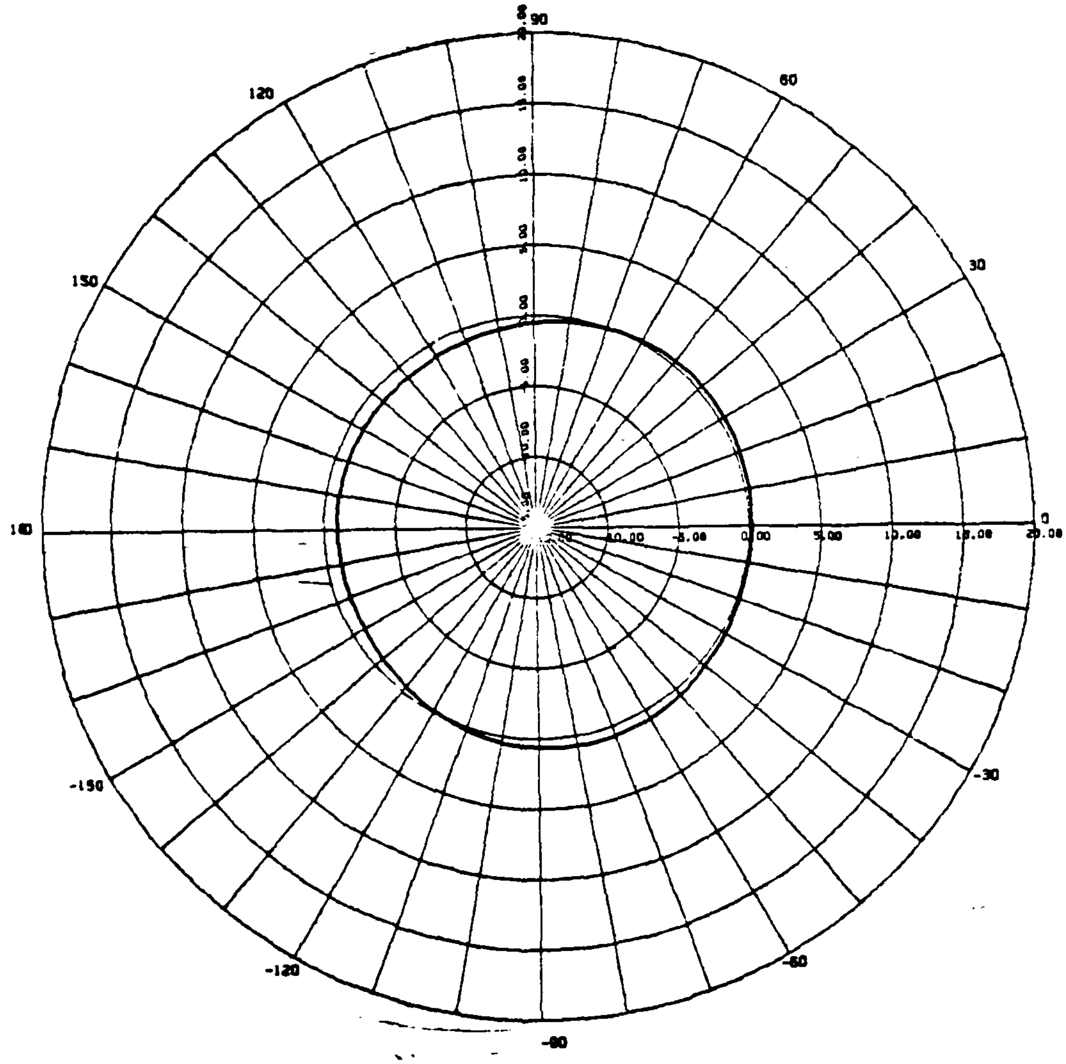
MRC-109 / PHI / THETA=90

PASTORAL / JEEP / 41 MHZ



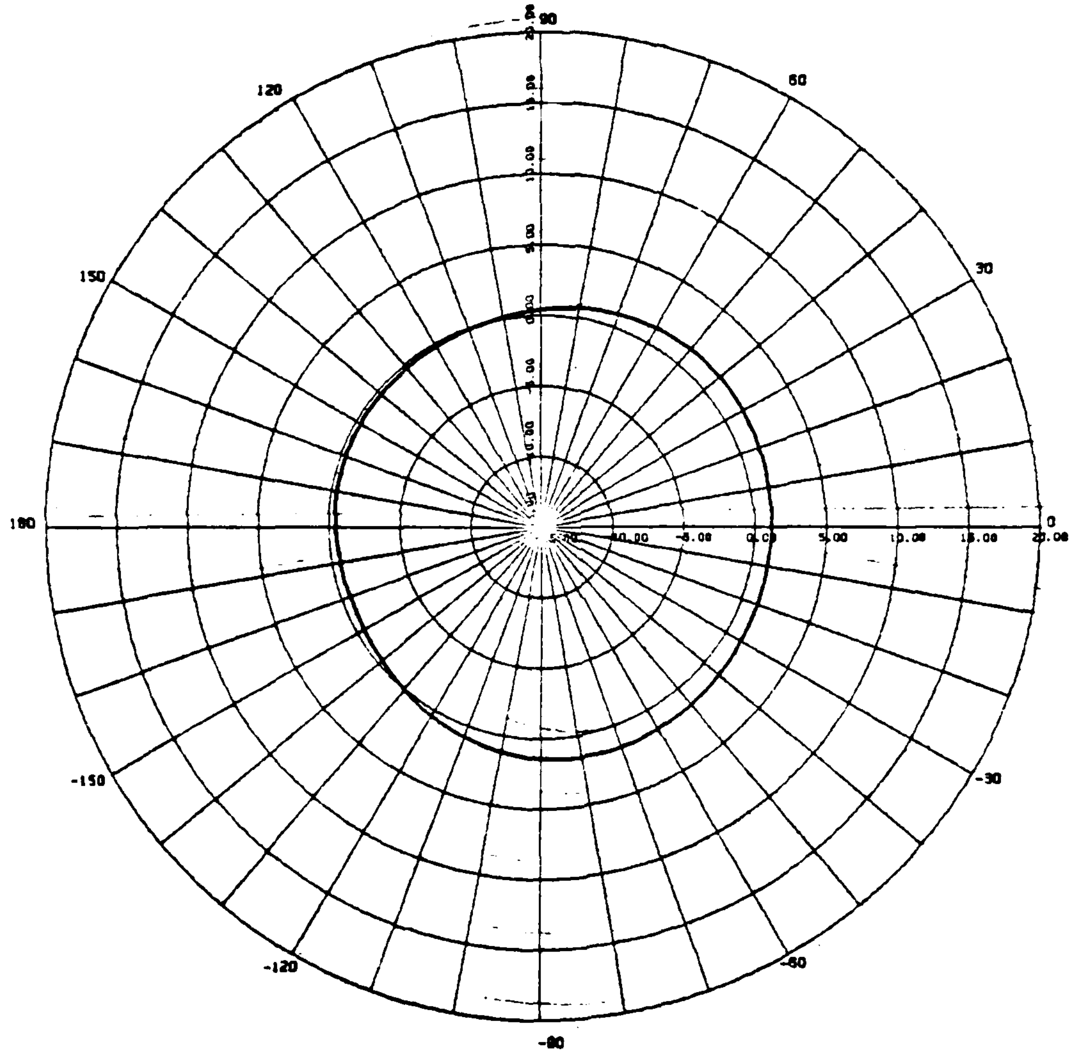
MAC-109 / PHI / THETA= 80

PASTORAL / JEEP / 41 MHZ



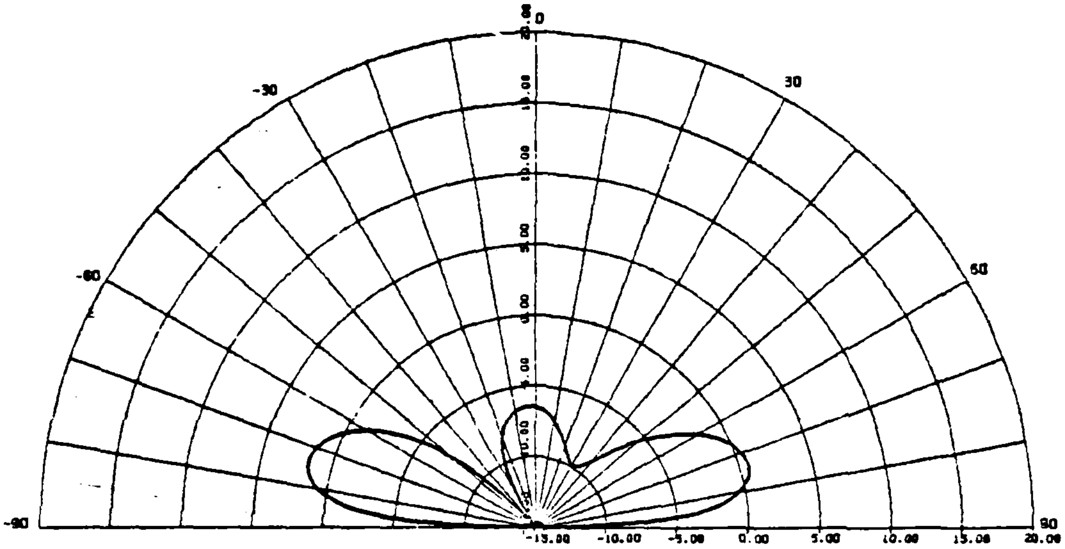
MRC-109 / PHI / THETA= 70

PASTORAL / JEEP / 41 MHZ



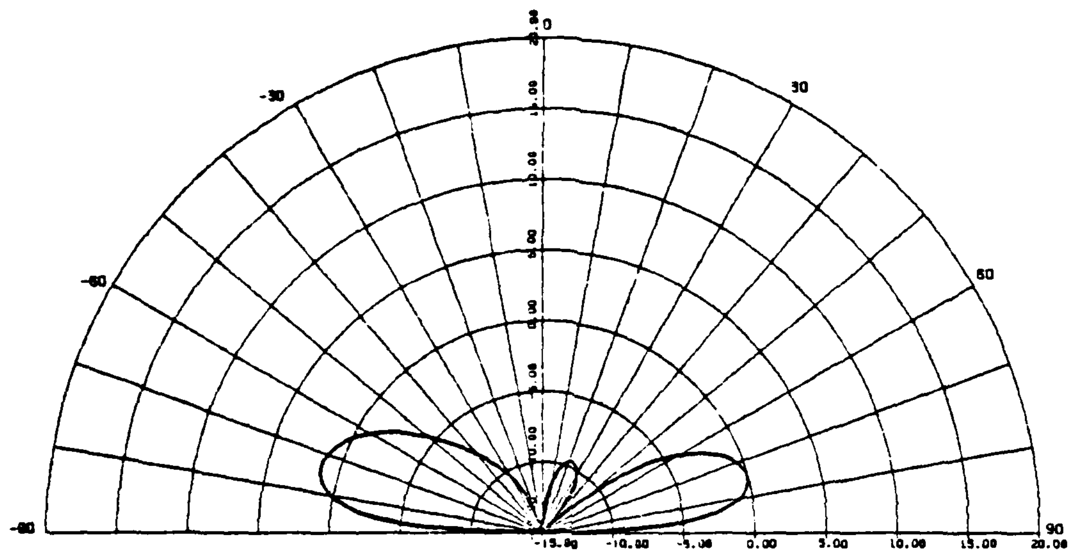
MRC-109 / THETA / PHI = 90

PASTORAL / JEEP / 41 MHZ



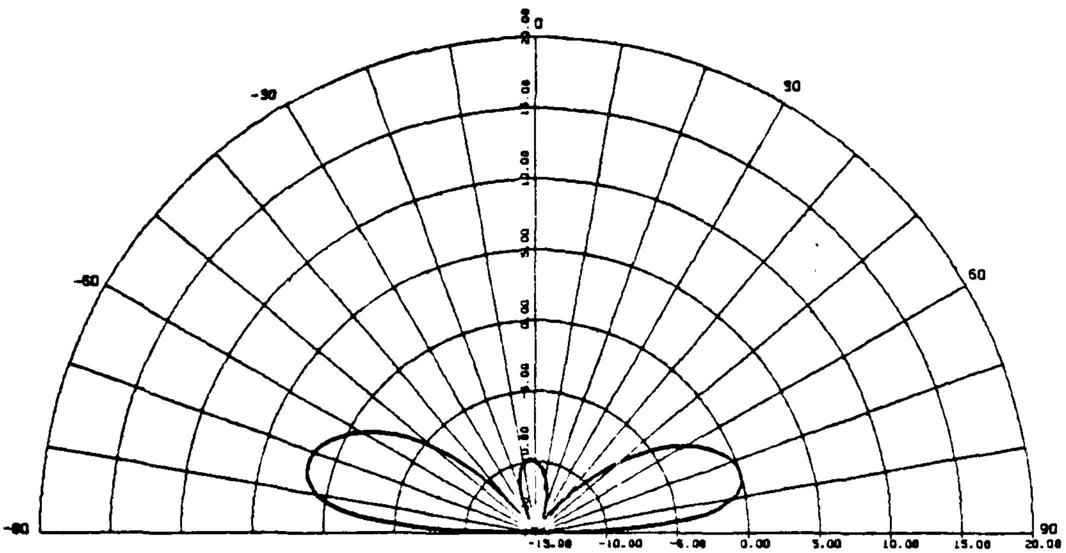
MAC-109 / THETA / PHI = 180

PASTORAL / JEEP / 41 MHZ



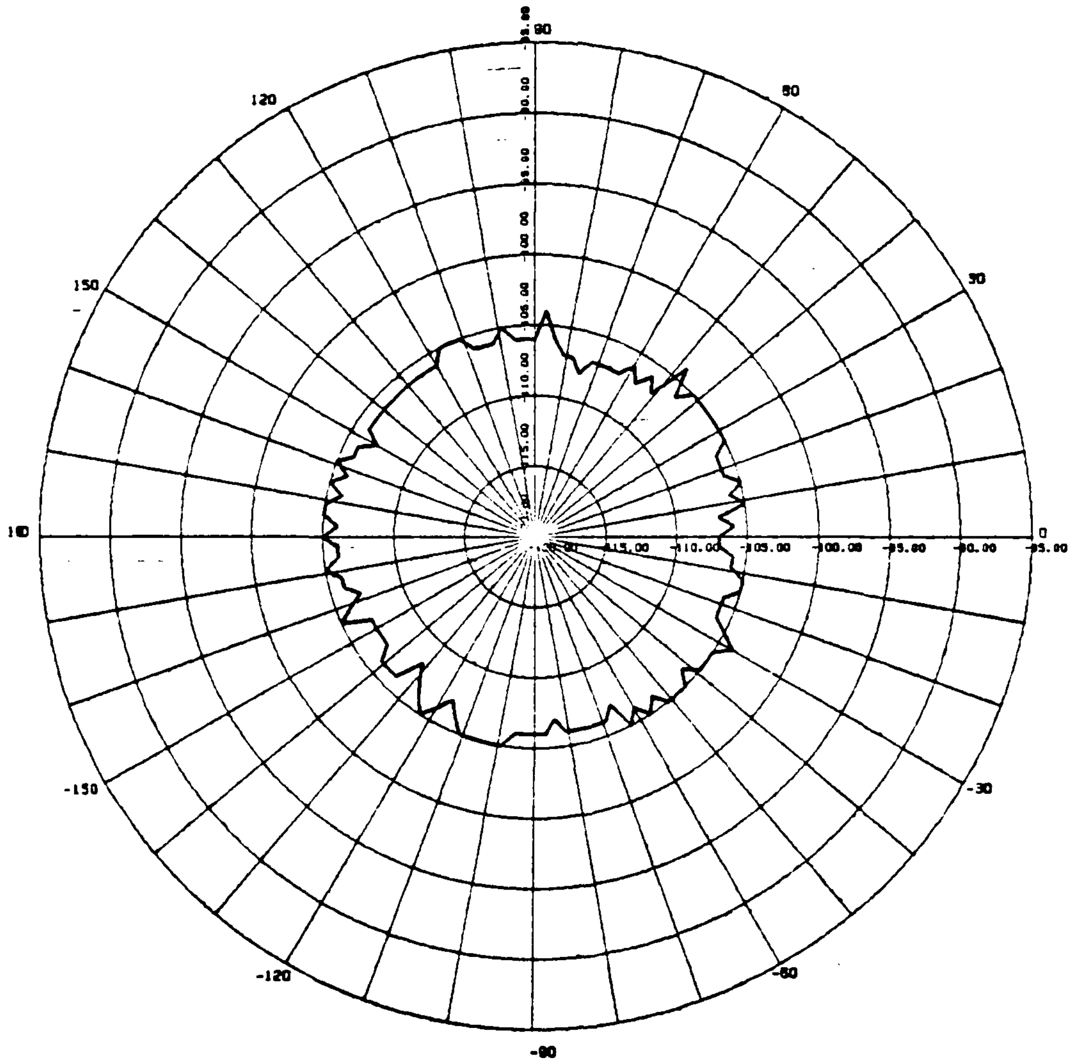
MAC-109 / THETA / PHI = 120

PASTORAL / JEEP / 41 MHZ



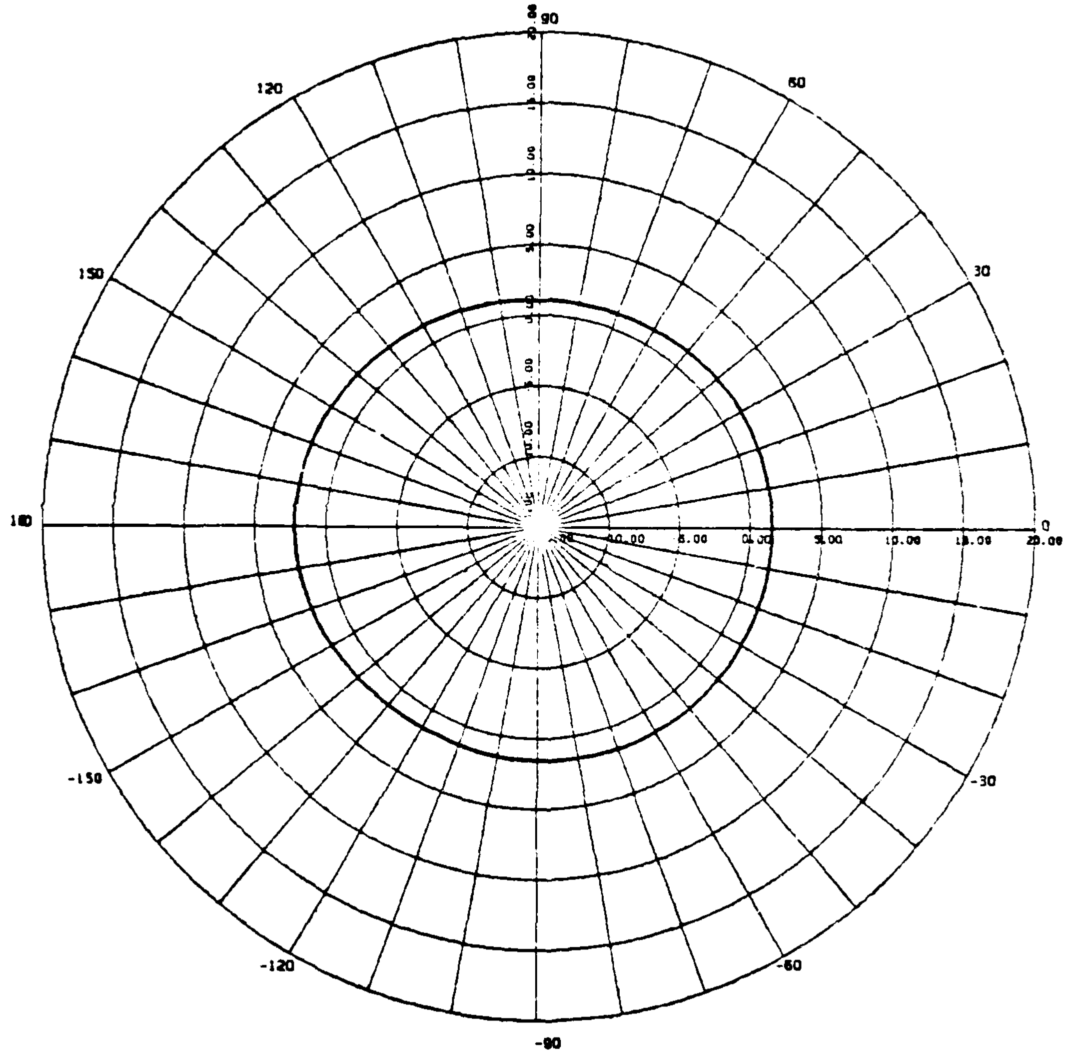
MAC-109 / PHI / THETA=90

PASTORAL / JEEP / 50 MHZ



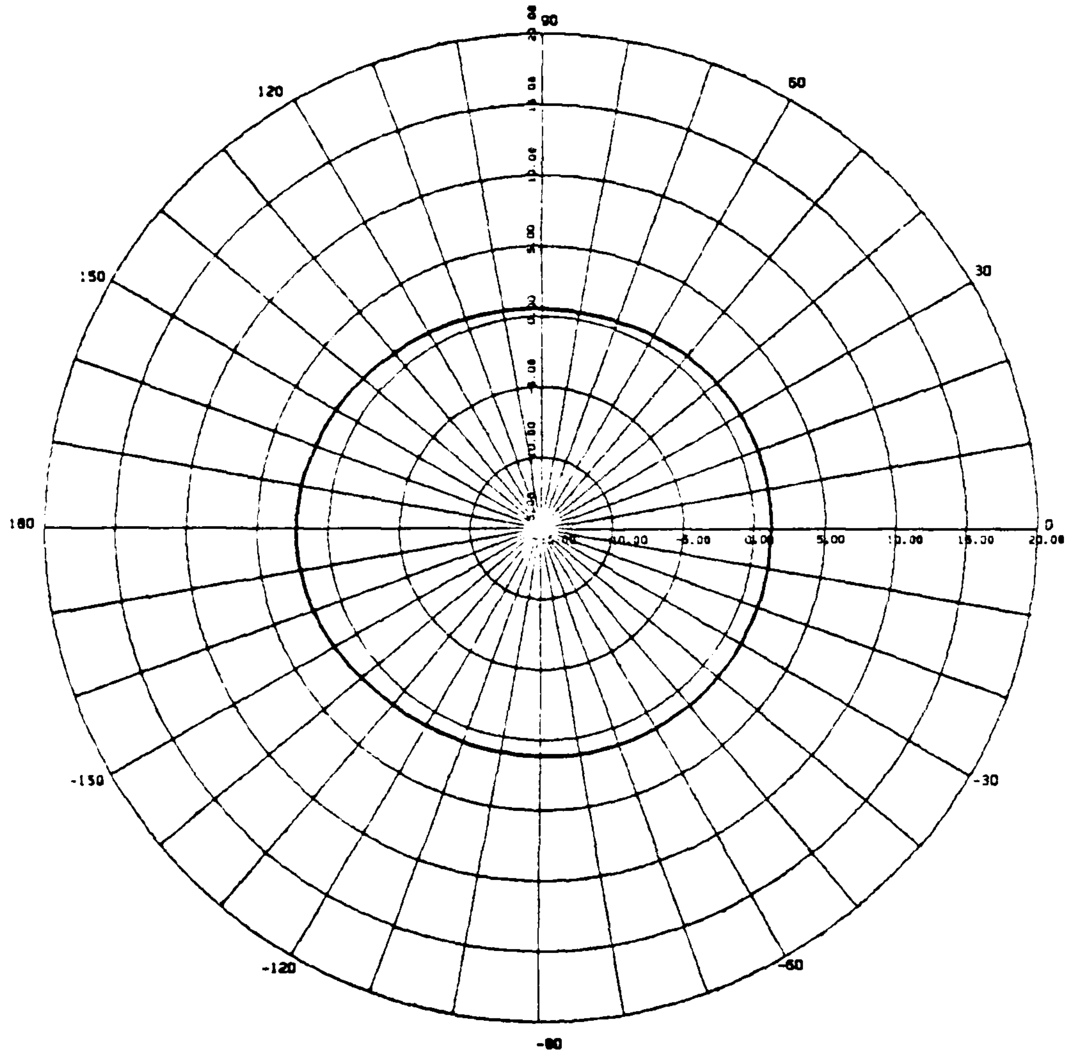
MAC-109 / PHI / THETA= 80

PASTORAL / JEEP / 50 MHZ



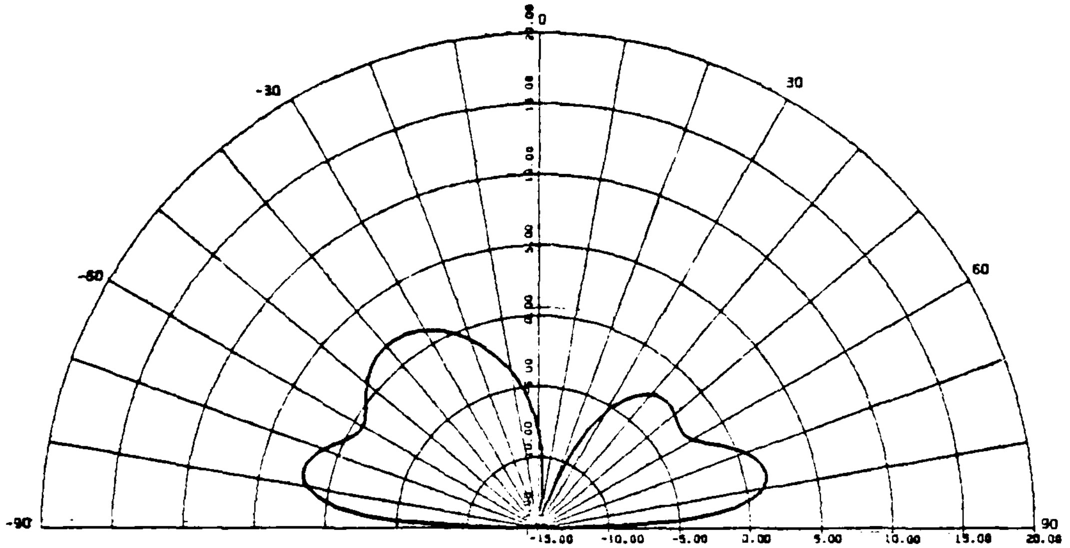
MAC-109 / PHI / THETA= 70

PASTORAL / JEEP / 50 MHZ



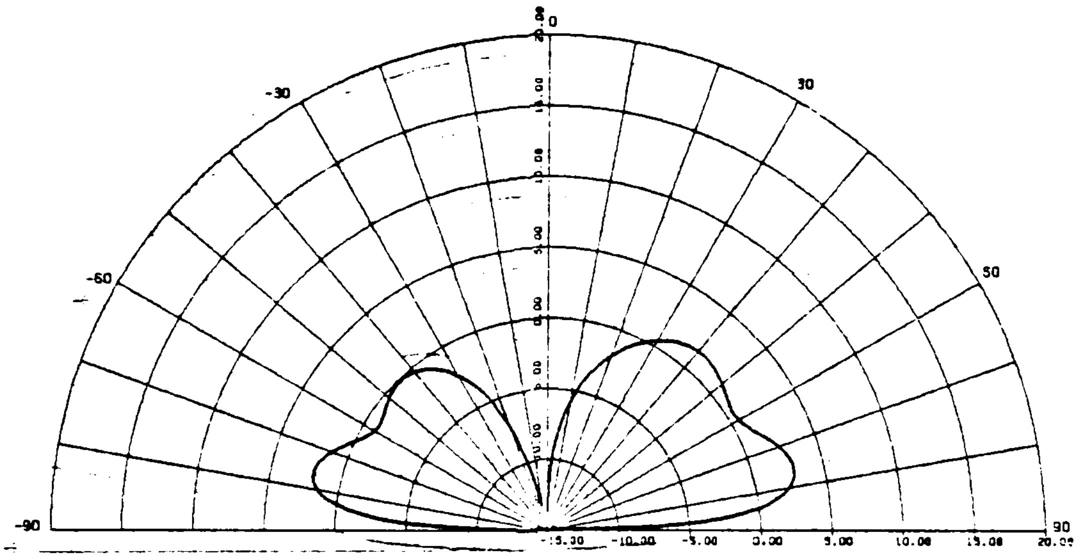
MRC-103 / THETA / PHI = 90

PASTORAL / JEEP / 50 MHZ



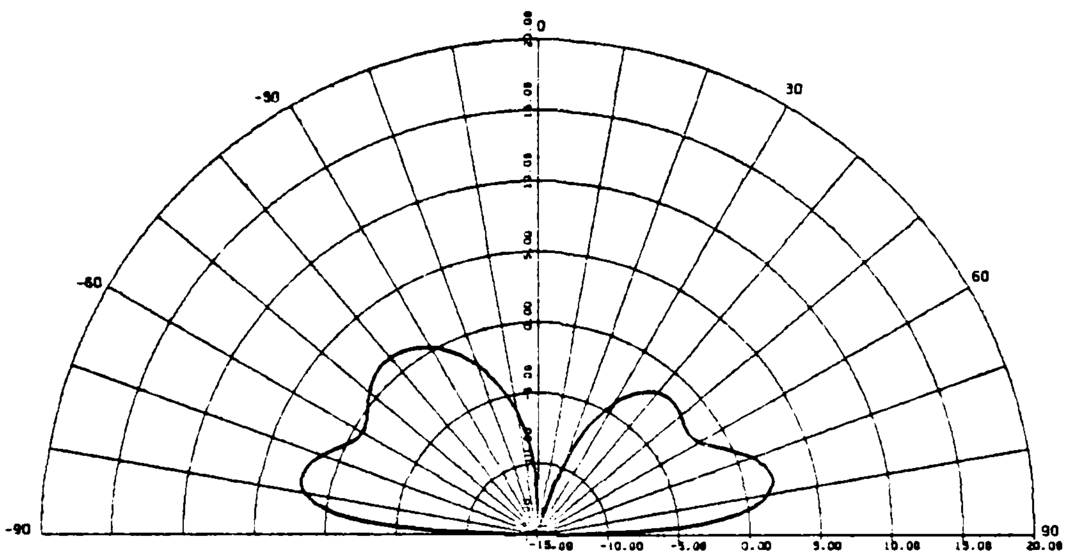
MRC-109 / THETA / PHI = 180

PASTORAL / JEEP / 50 MHZ



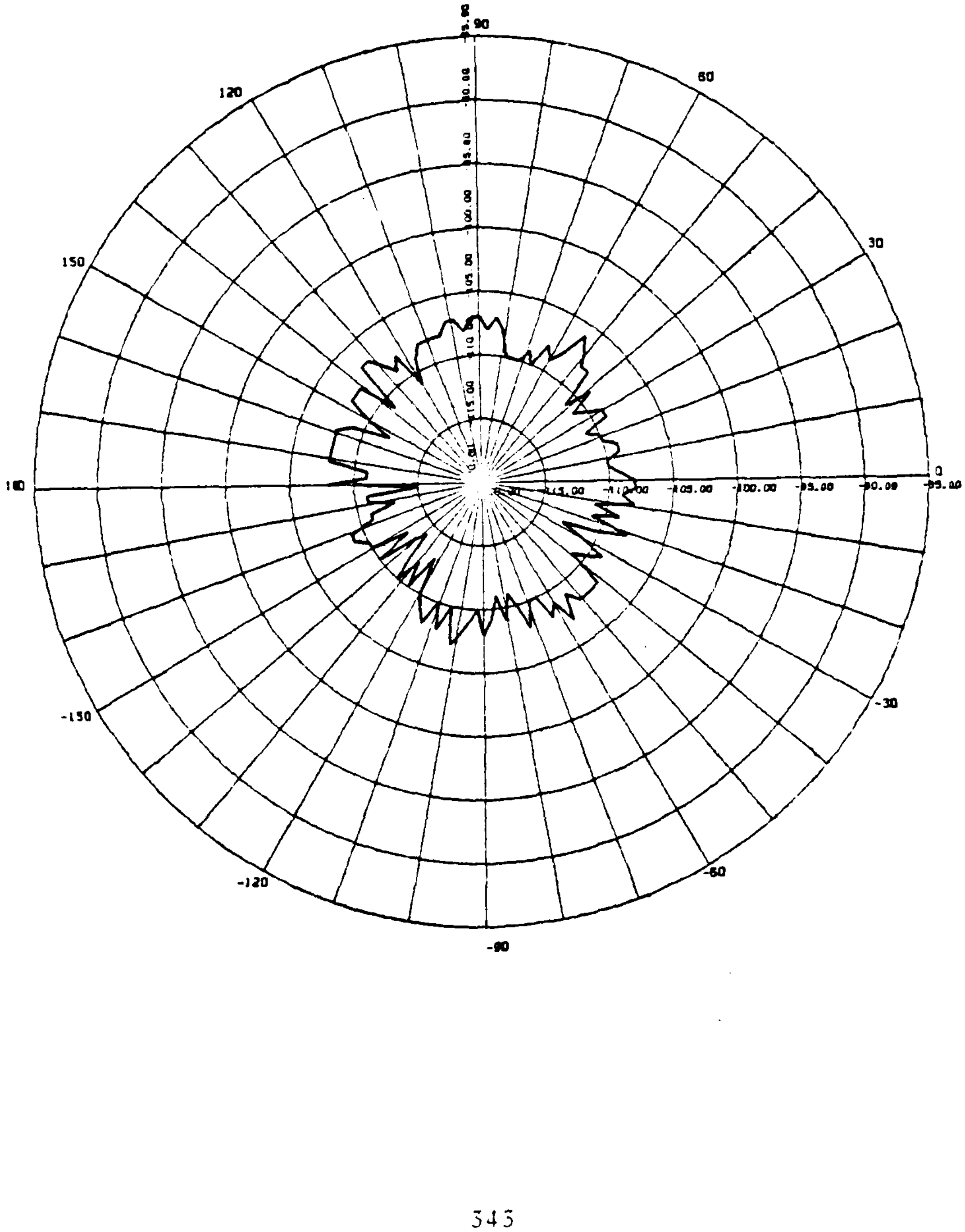
MRC-109 / THETA / PHI = 120

PASTORAL / JEEP / 50 MHZ



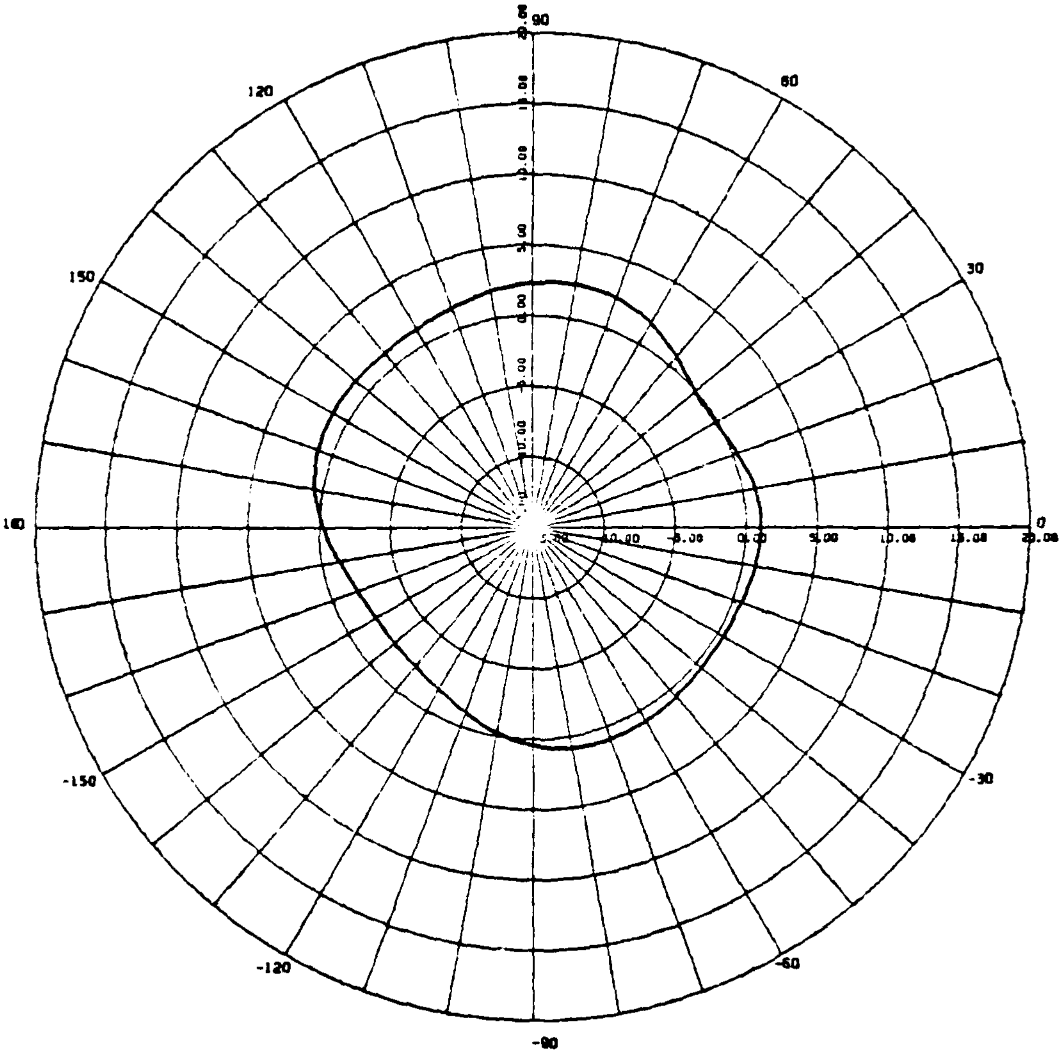
MAC-109 / PHI / THETA=90

PASTORAL / JEEP / 75 MHZ



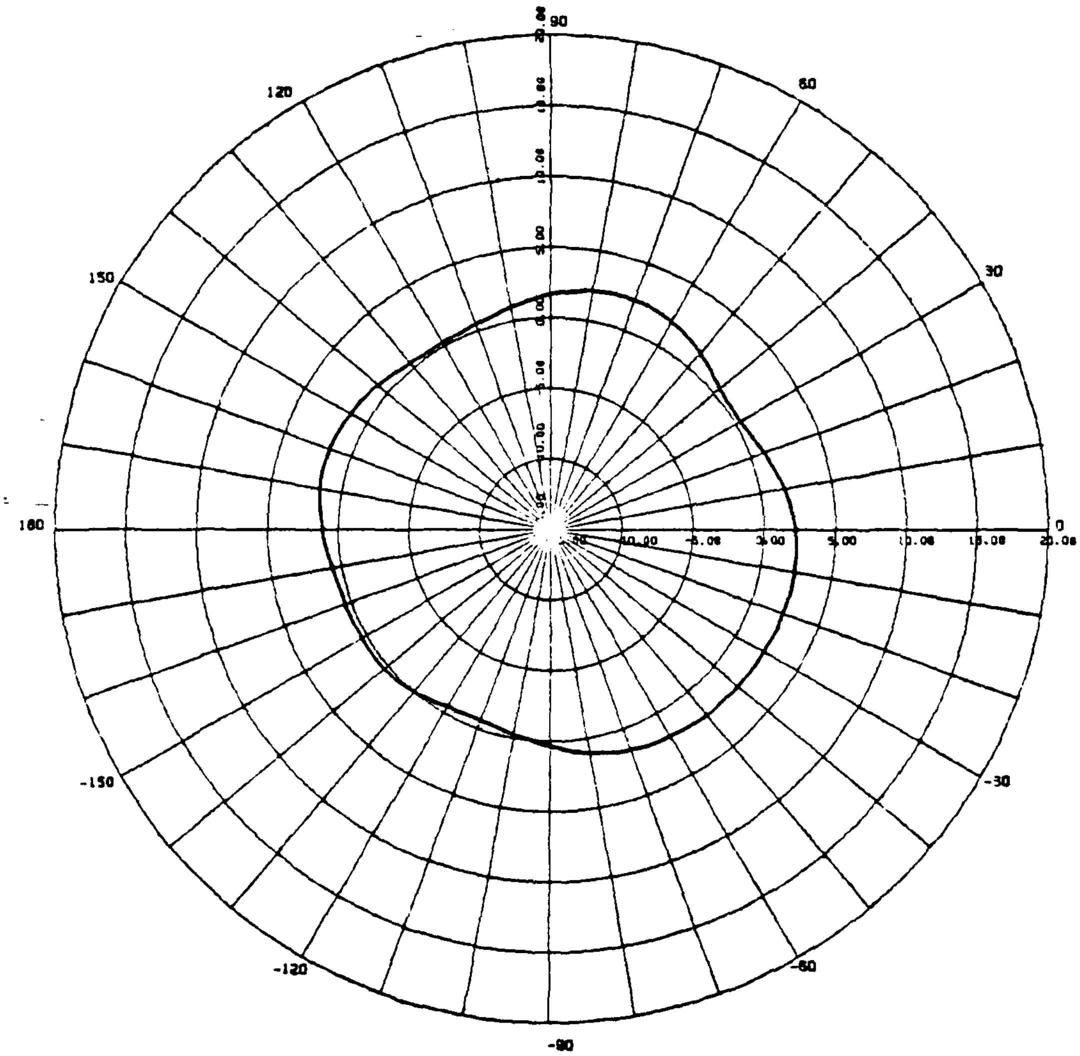
MAC-109 / PHI / THETA= 80

PASTORAL / JEEP / 75 MHZ



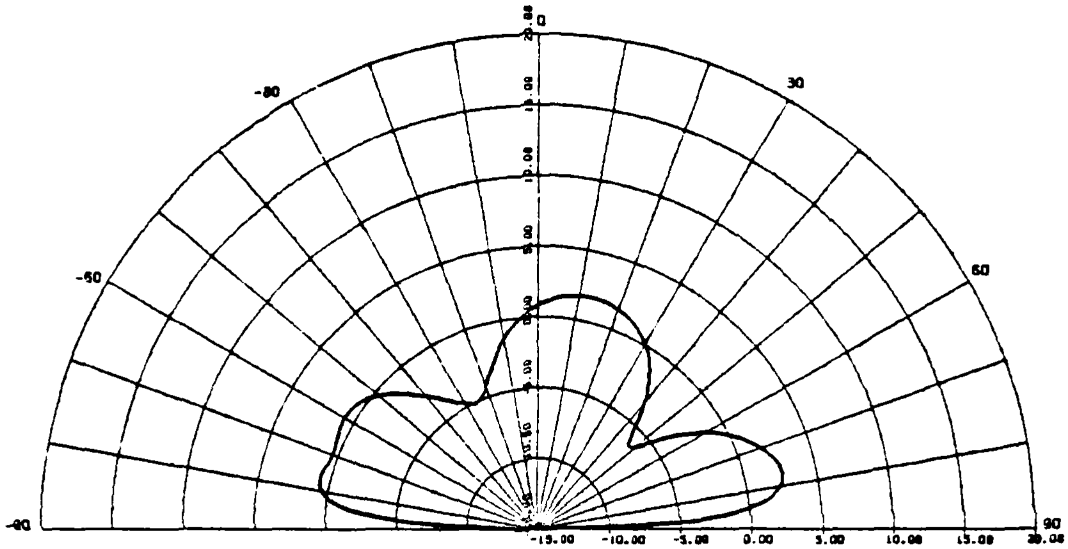
MAC-109 / PHI / THETA= 70

PASTORAL / JEEP / 75 MHZ



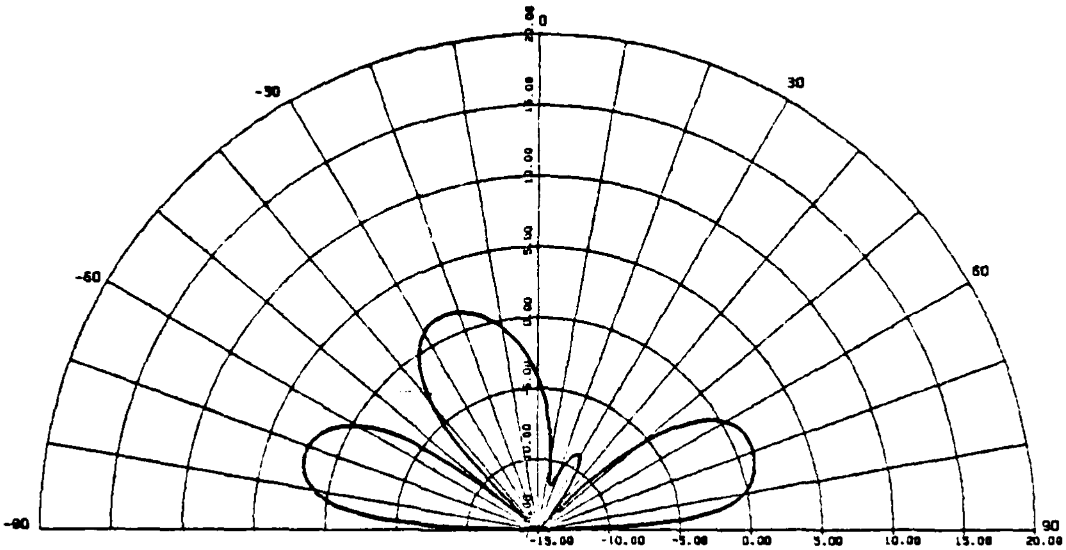
MRC-109 / THETA / PHI = 90

PASTORAL / JEEP / 75 MHZ



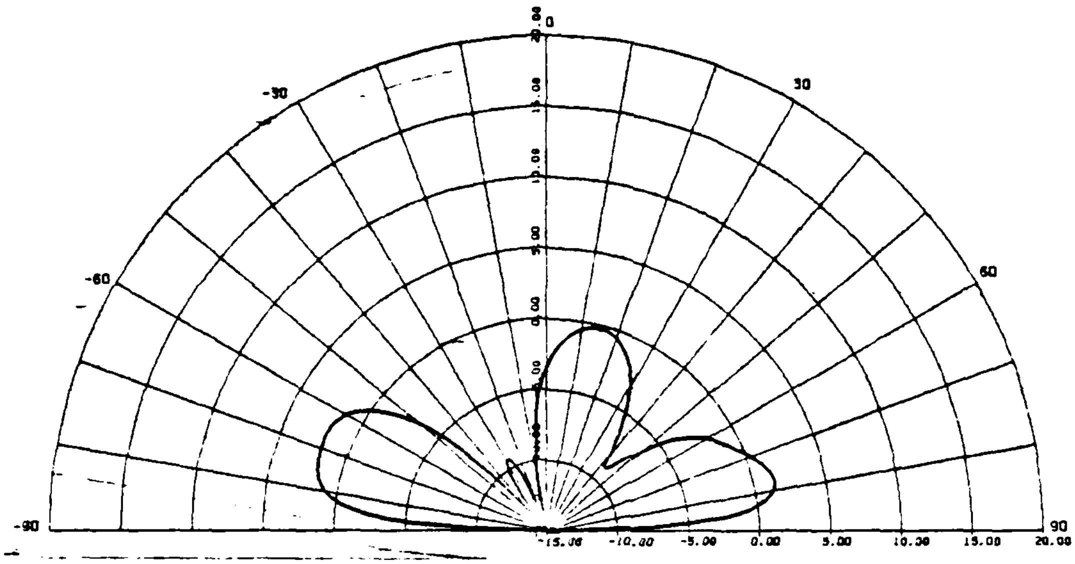
MAC-109 / THETA / PHI = 180

PASTORAL / JEEP / 75 MHZ



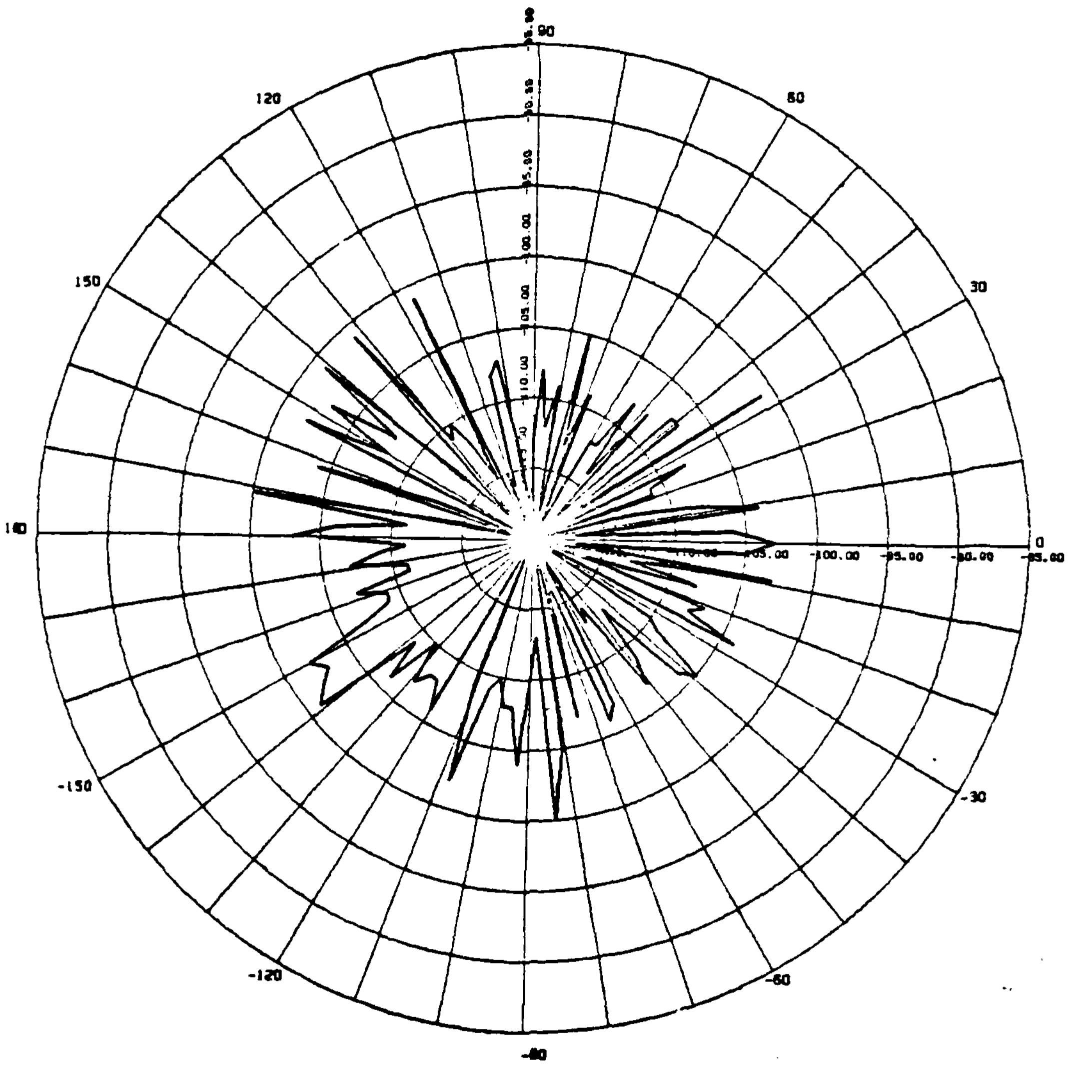
MAC-109 / THETA / PHI = 120

PASTORAL / JEEP / 75 MHZ



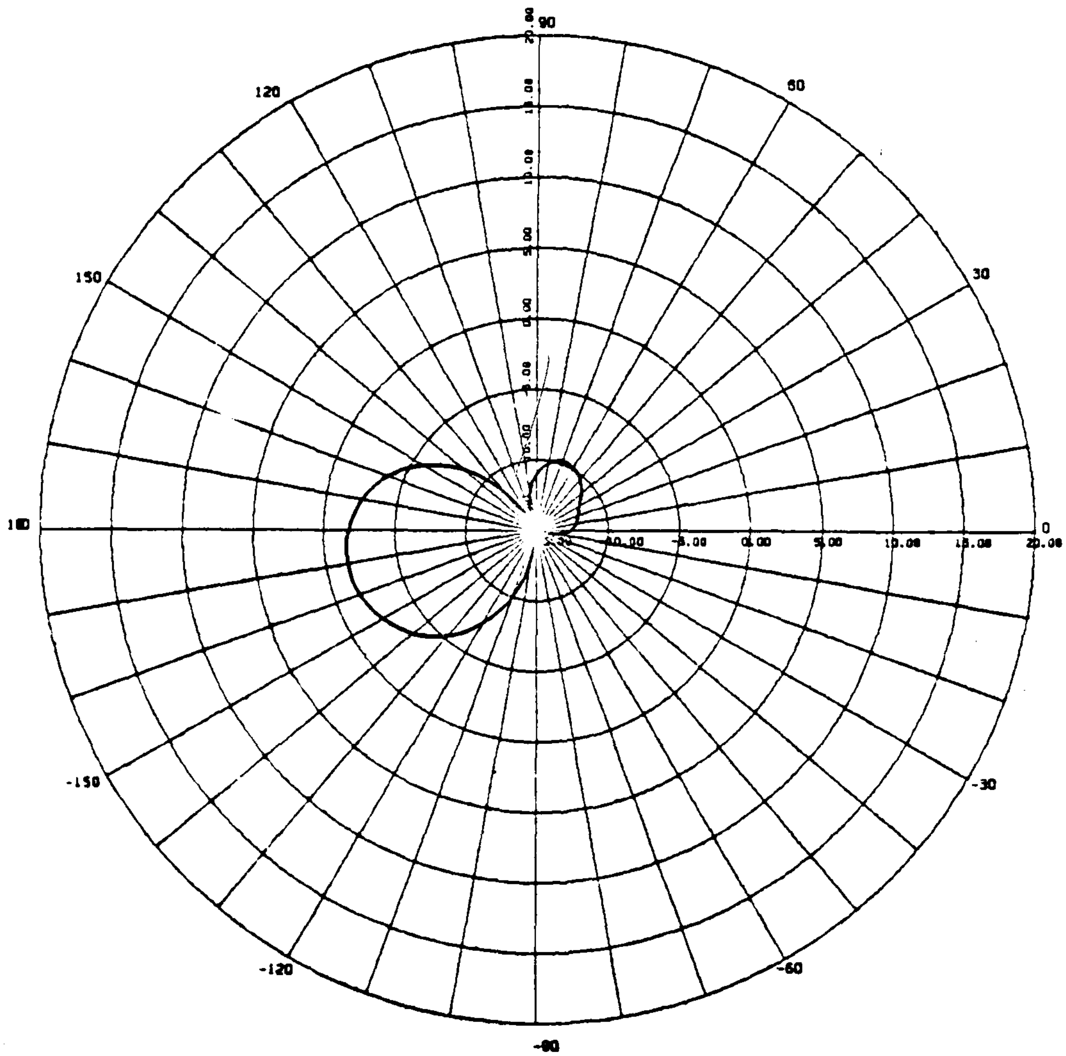
MAC-109 / PHI / THETA=90

PASTORAL / JEEP & TALA / 30 MHZ



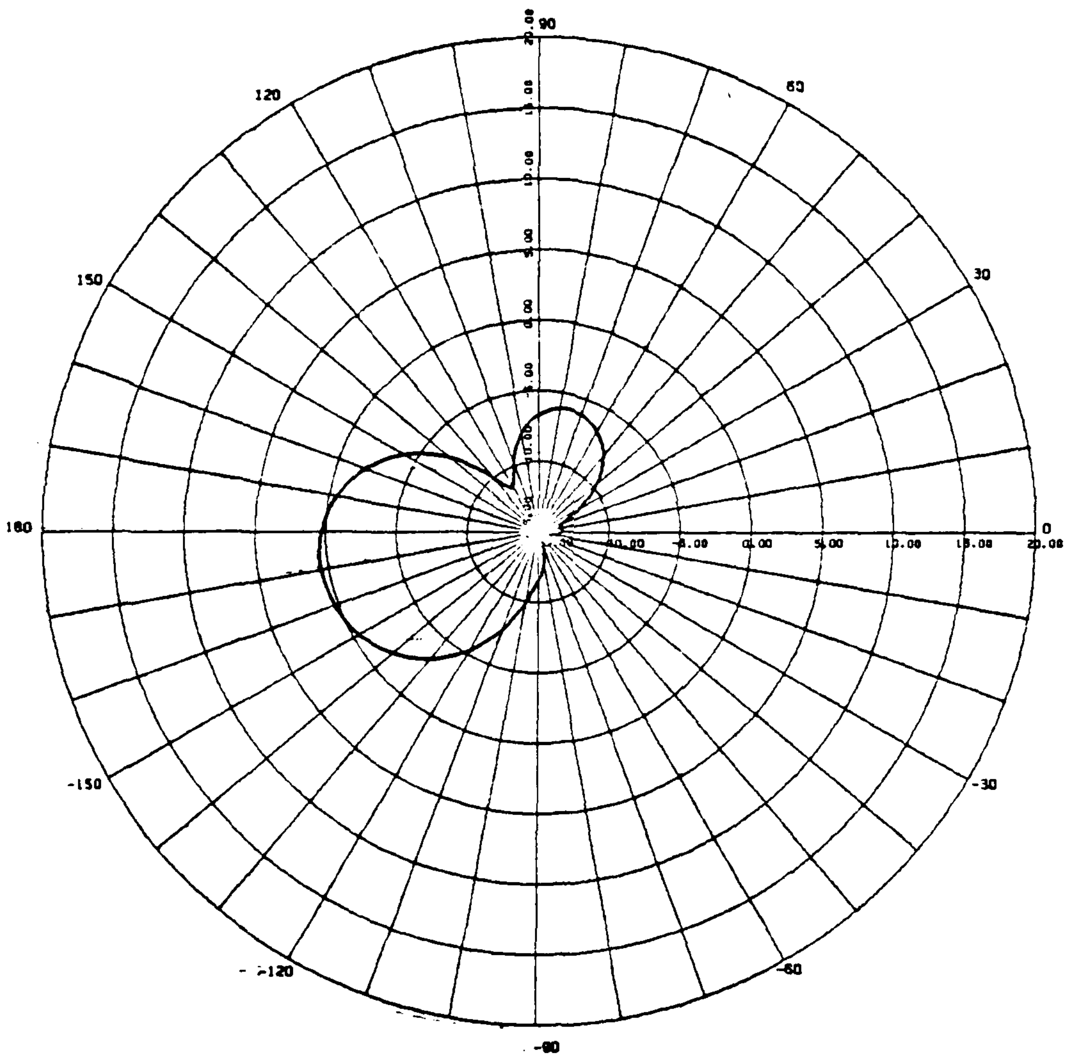
MAC-109 / PHI / THETA=80

PASTORAL / JEEP & TRLR / 30 MHZ



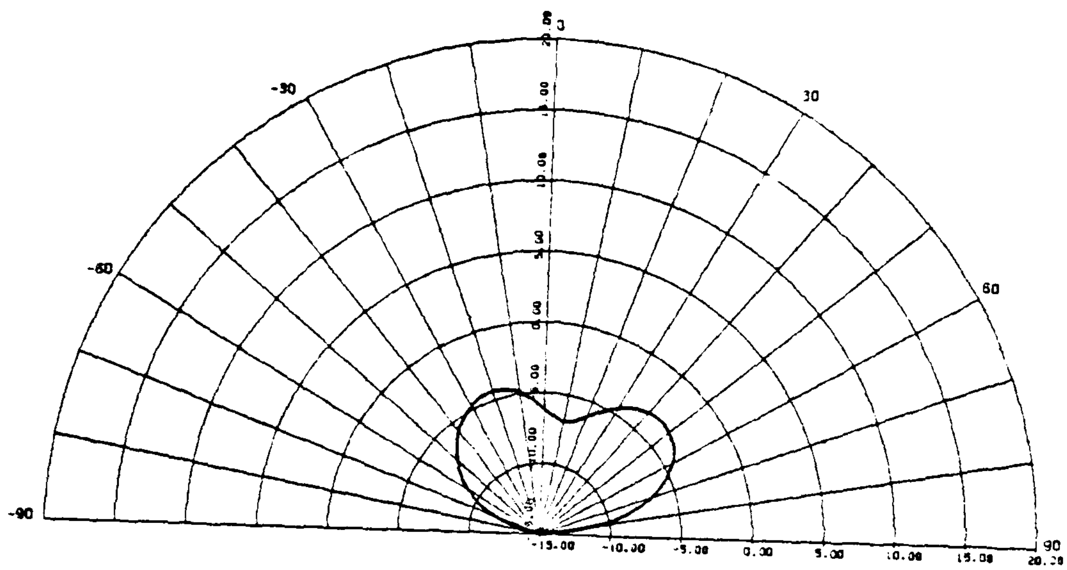
MRC-109 / PHI / THETA=70

PASTORAL / JEEP & TRLR / 30 MHZ



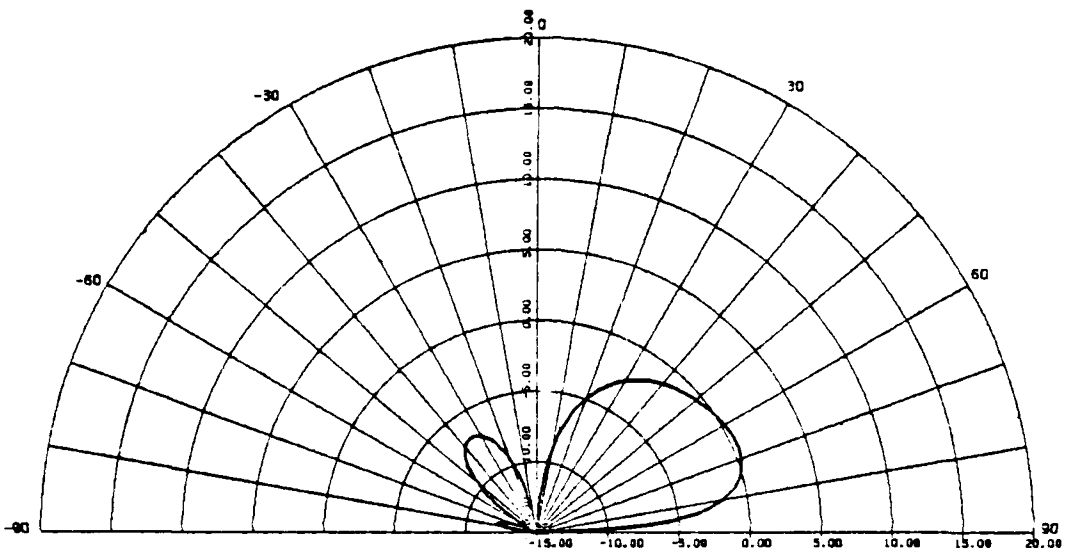
MAC-108 / THETA / PHI=90

PASTORAL / JEEP & TALA / 30 MHZ



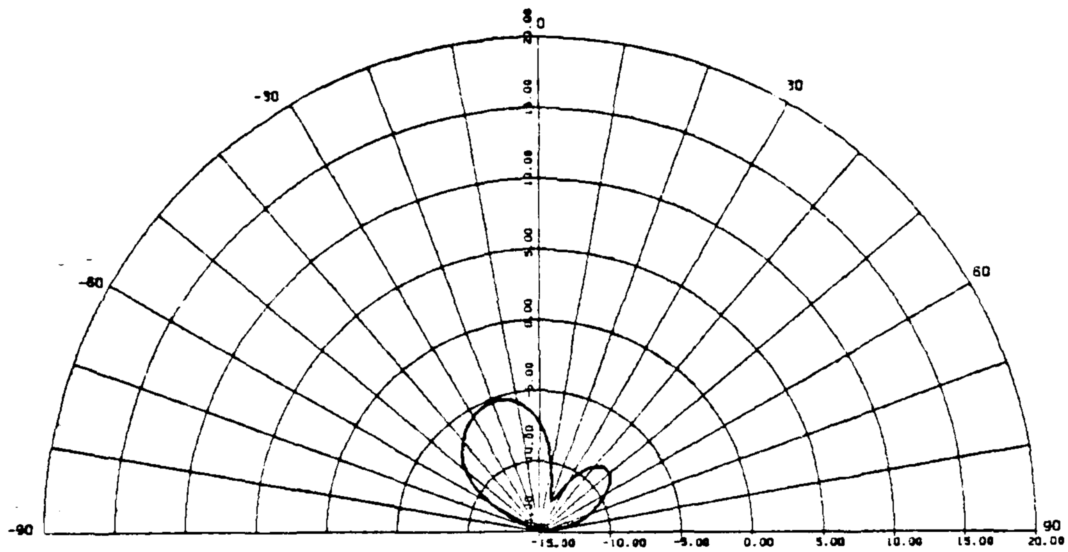
MRC-109 / THETA / PHI=180

PASTORAL / JEEP & TALR / 30 MHZ



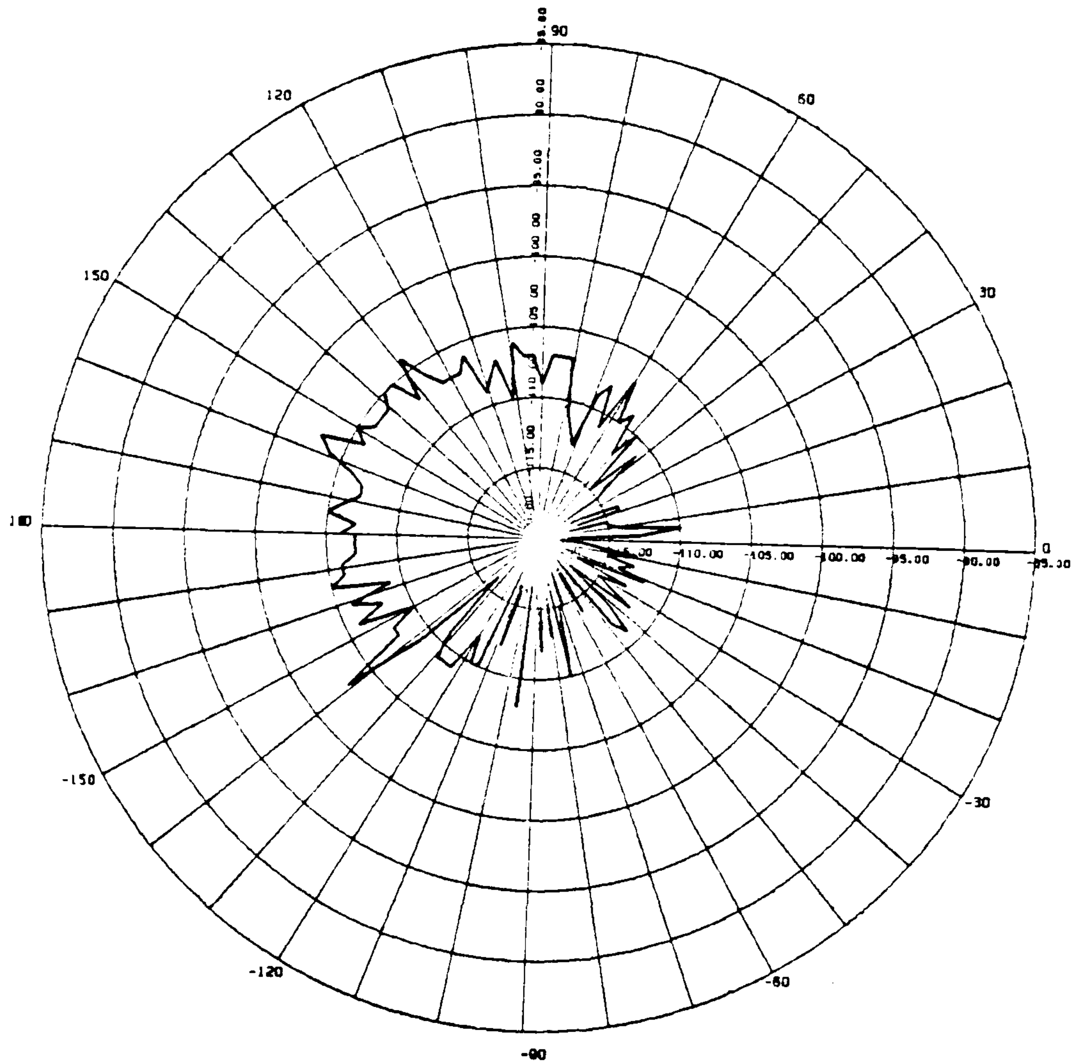
MRC-109 / THETA / PHI=120

PASTORAL / JEEP & TALA / 30 MHZ



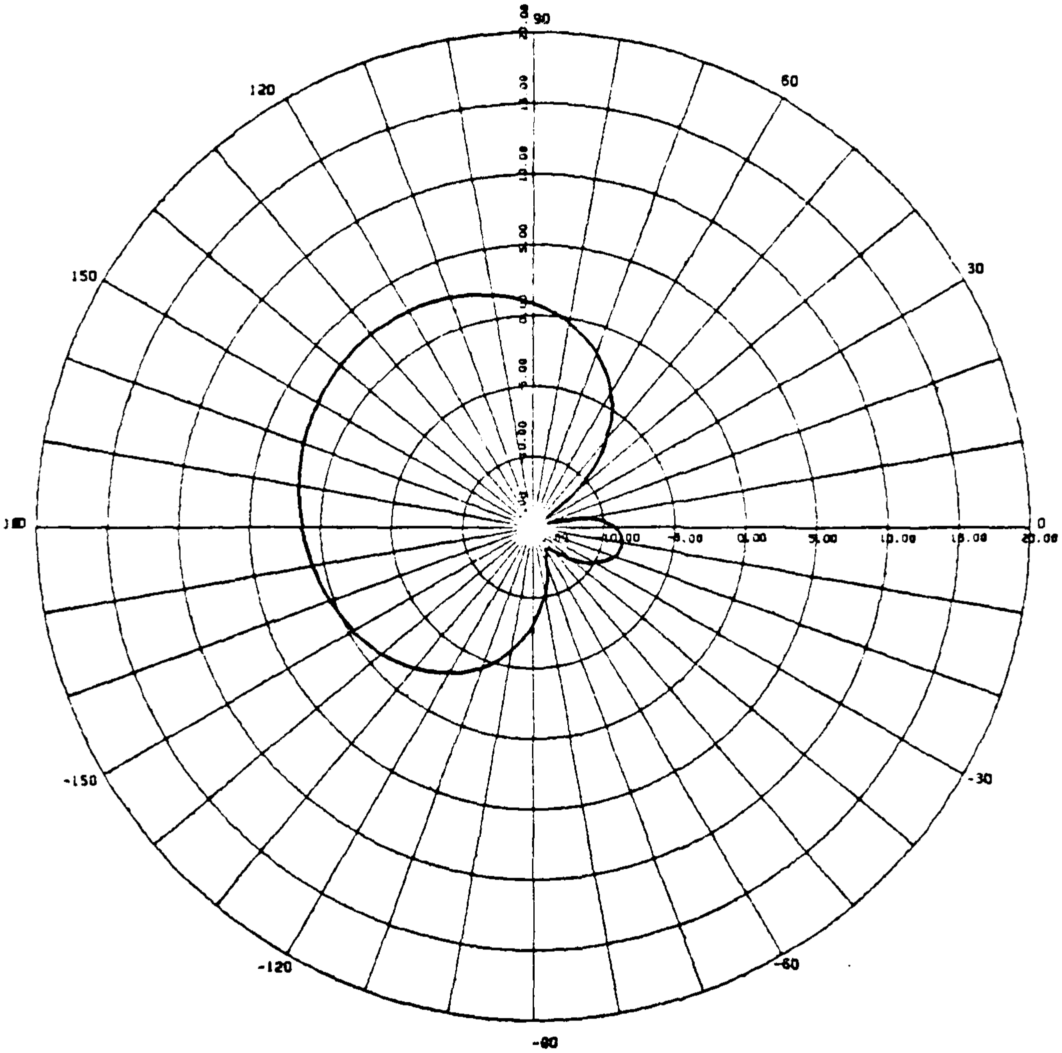
MAC-109 / PHI / THETA=90

PASTORAL / JEEP & TALA / 41 MHZ



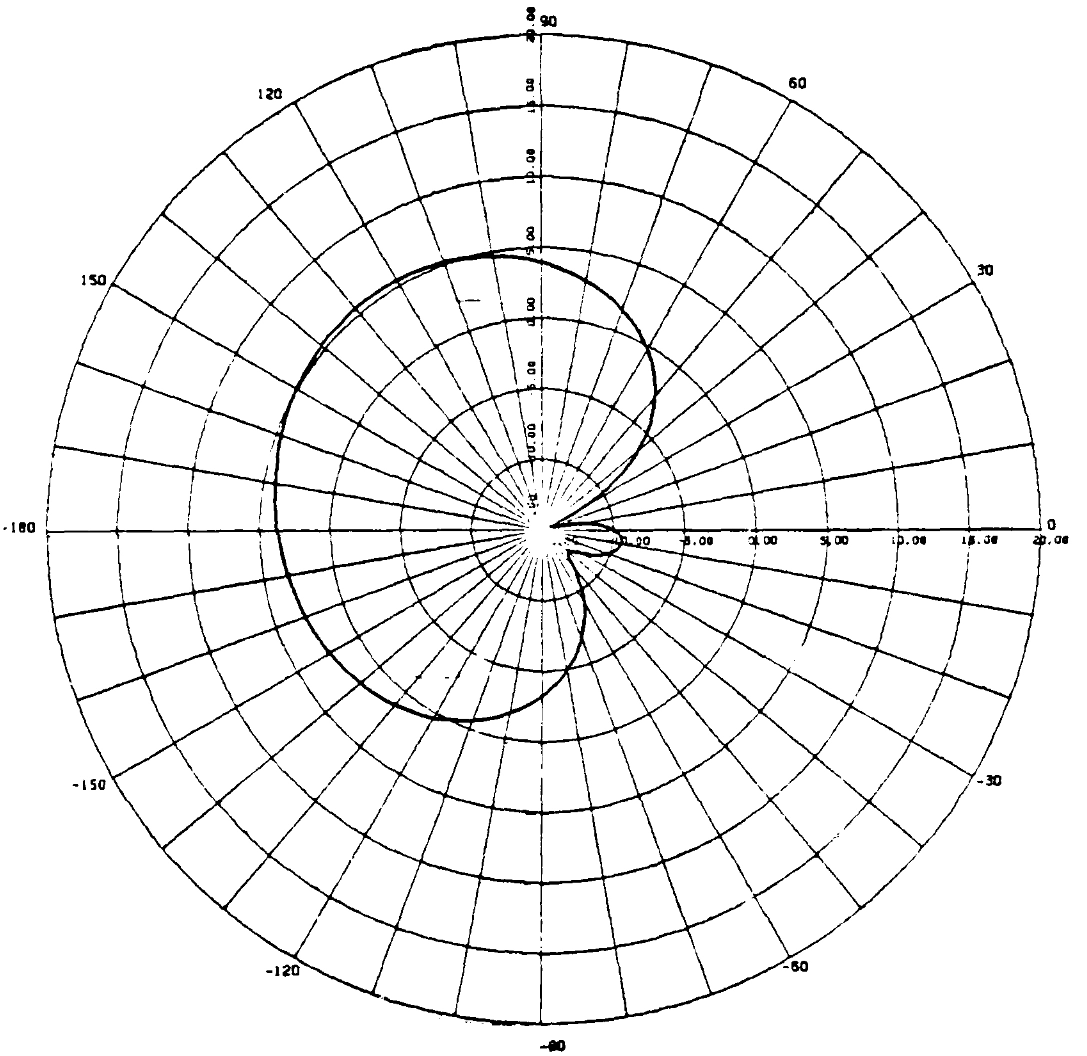
MAC-109 / PHI / THETA=90

PASTORAL / JEEP & TRLR / 41 MHZ



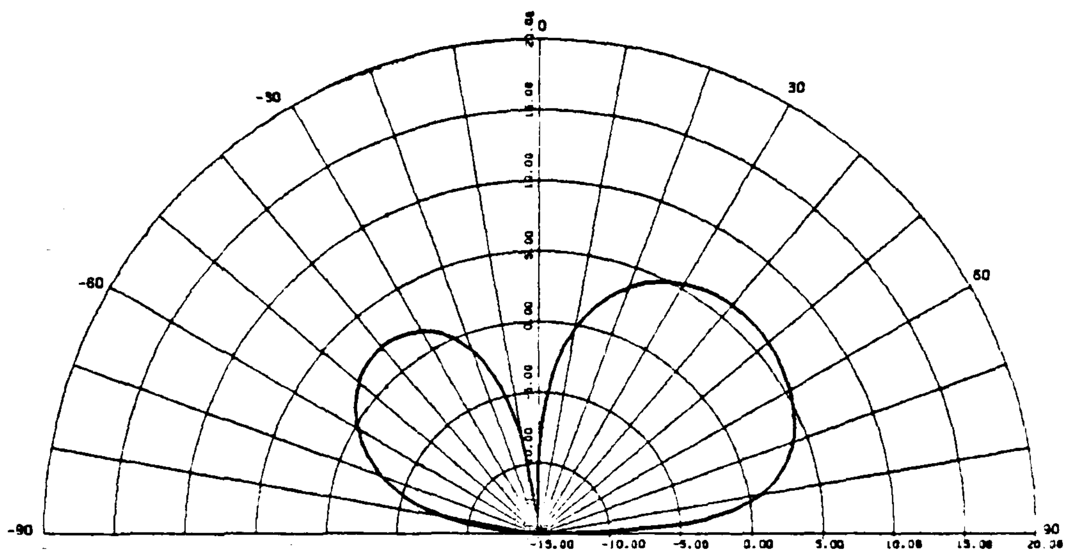
MRC-109 / PHI / THETA=70

PASTORAL / JEEP & TRLR / 41 MHZ



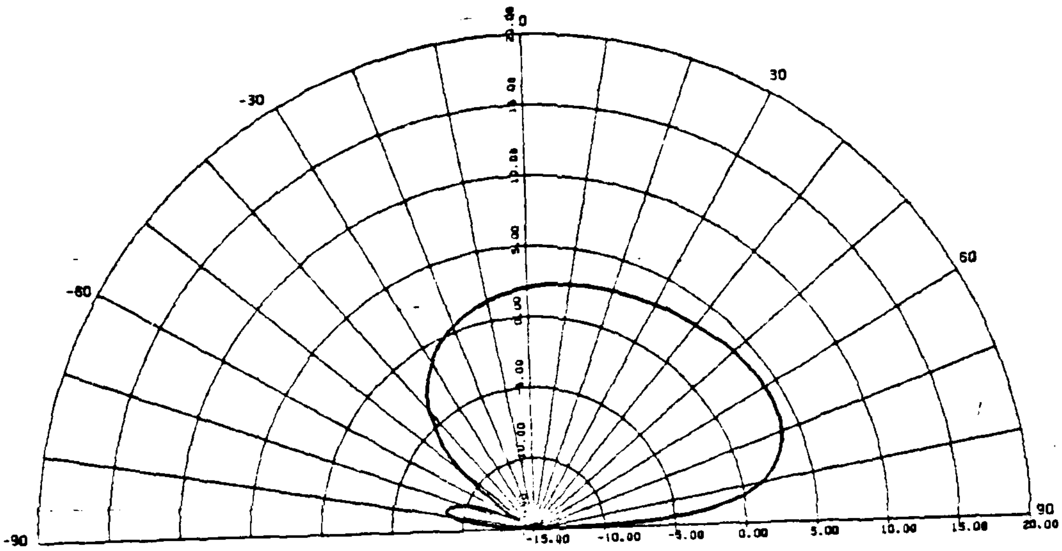
MAC-109 / THETA / PHI=90

PASTORAL / JEEP & TALA / 41 MHZ



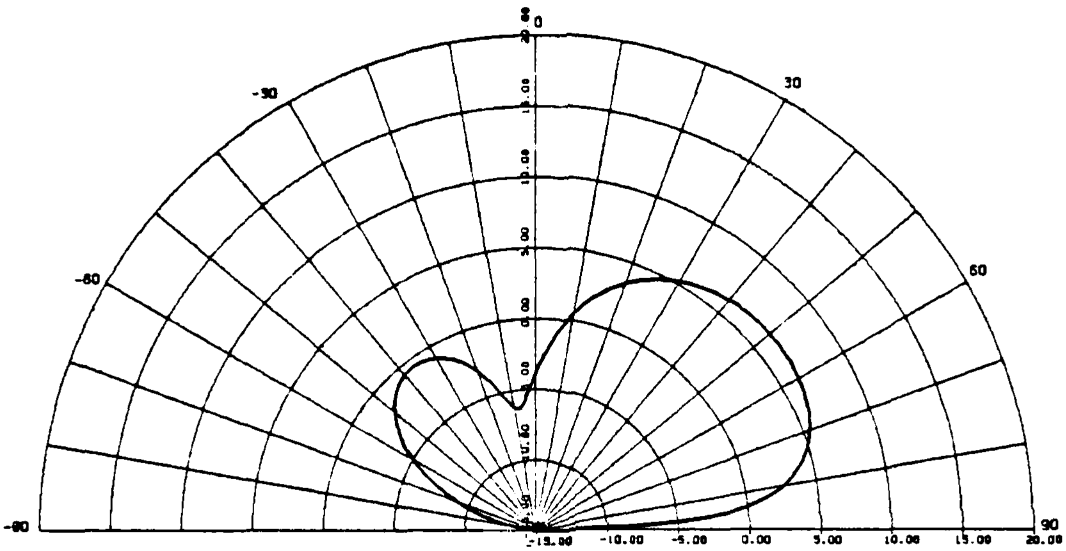
MAC-109 / THETA / PHI=180

PASTORAL / JEEP & TALA / 41 MHZ



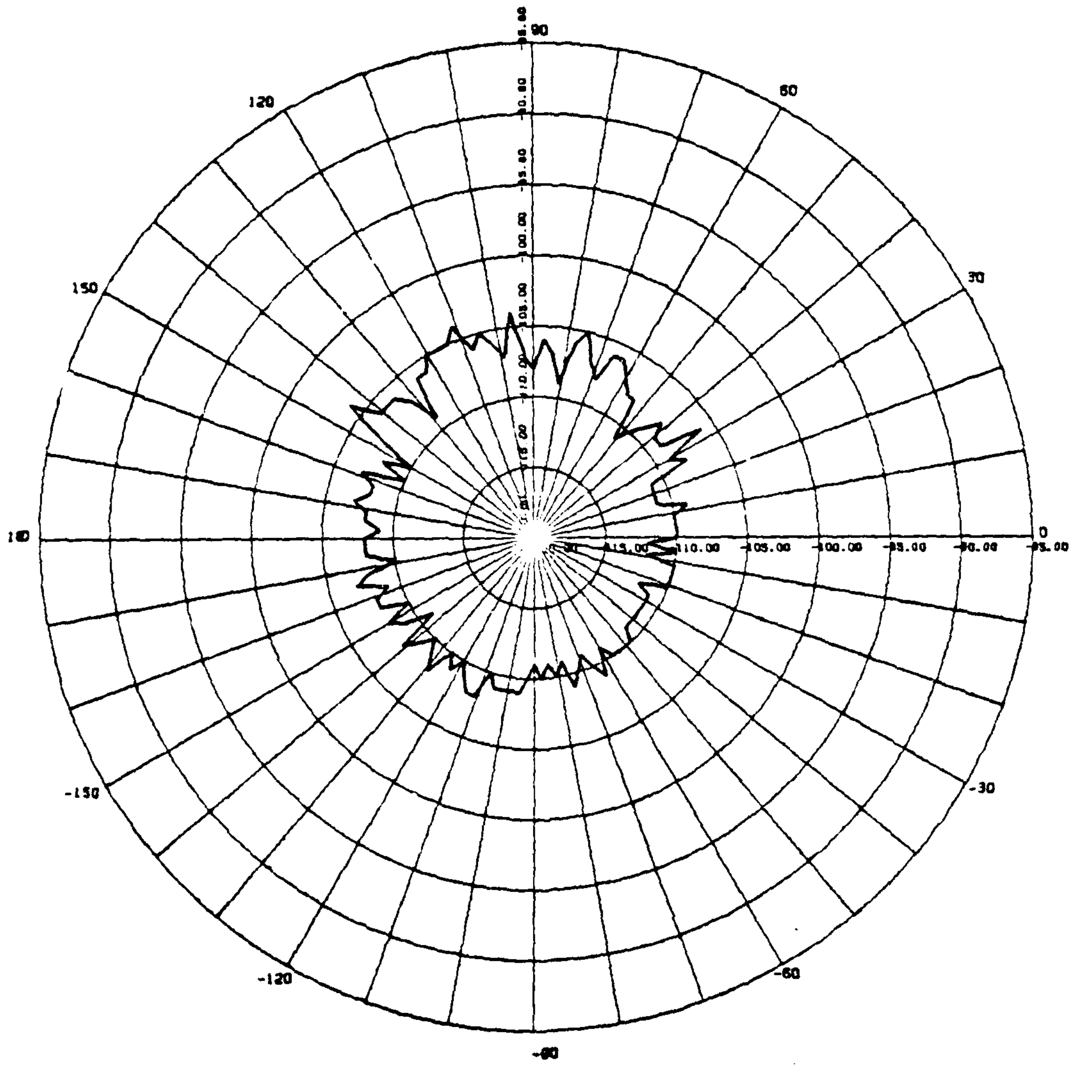
MRC-109 / THETA / PHI=120

PASTORAL / JEEP & TRLR / 41 MHZ



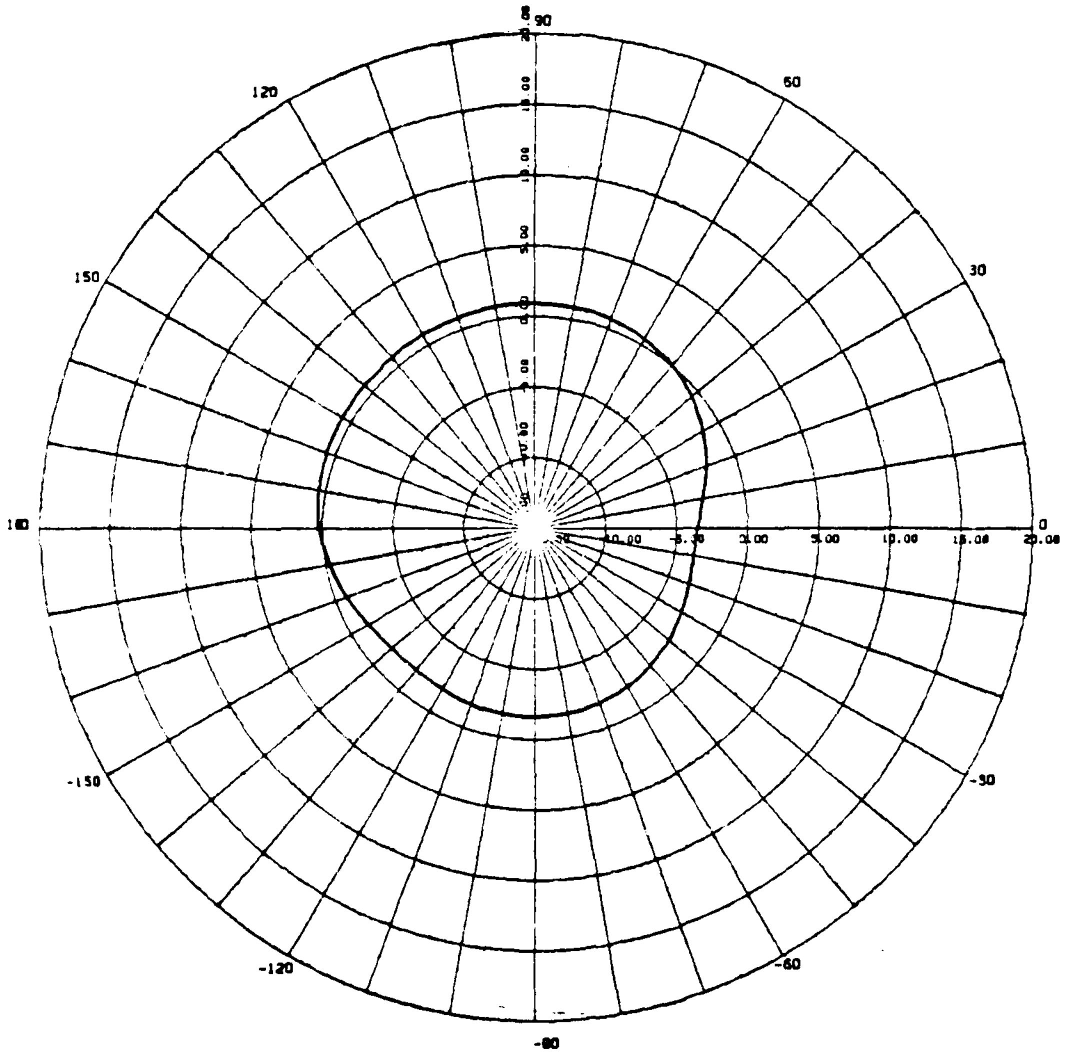
MRC-109 / PHI / THETA=90

PASTORAL / JEEP & TALA / 50 MHZ



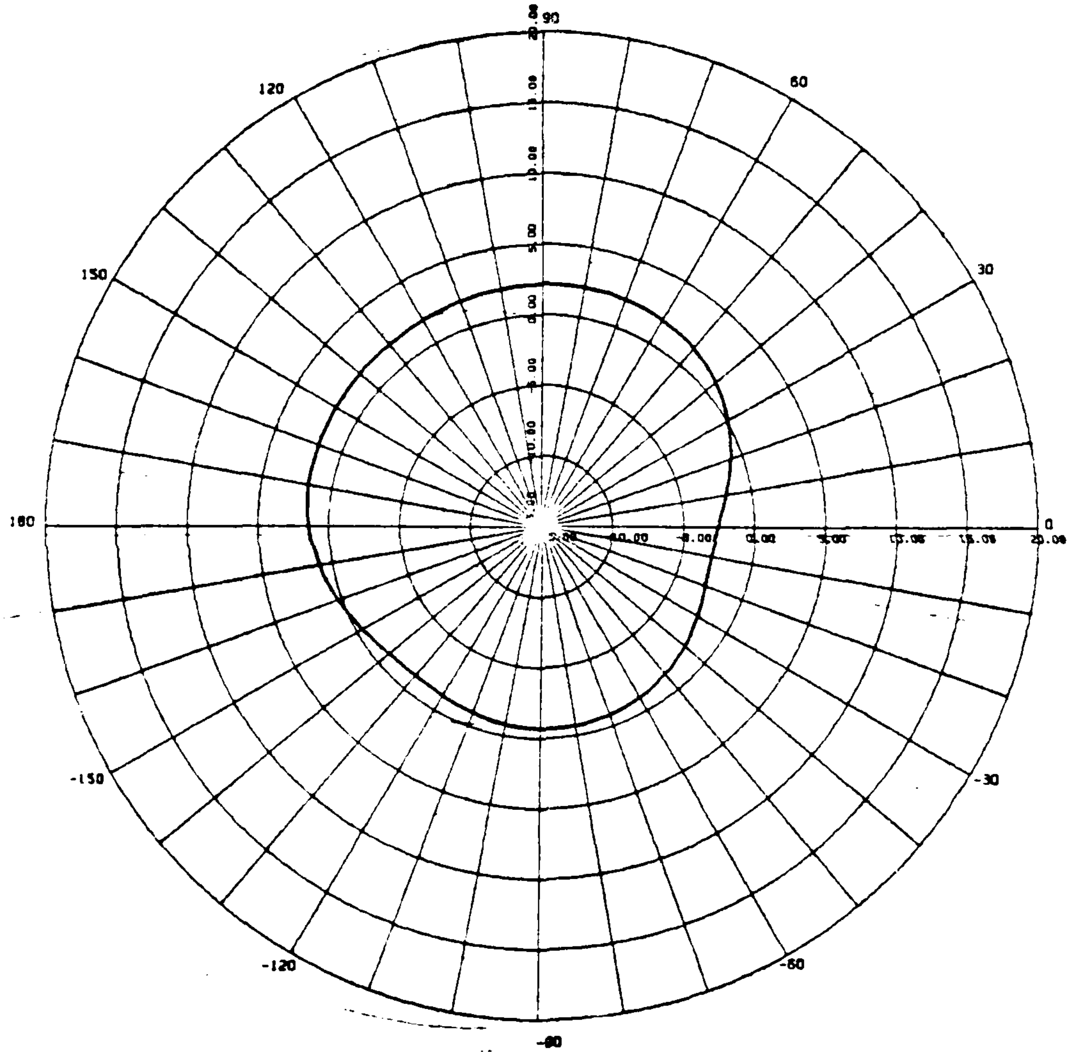
MAC-109 / PHI / THETA=80

PASTORAL / JEEP & TALA / 50 MHZ



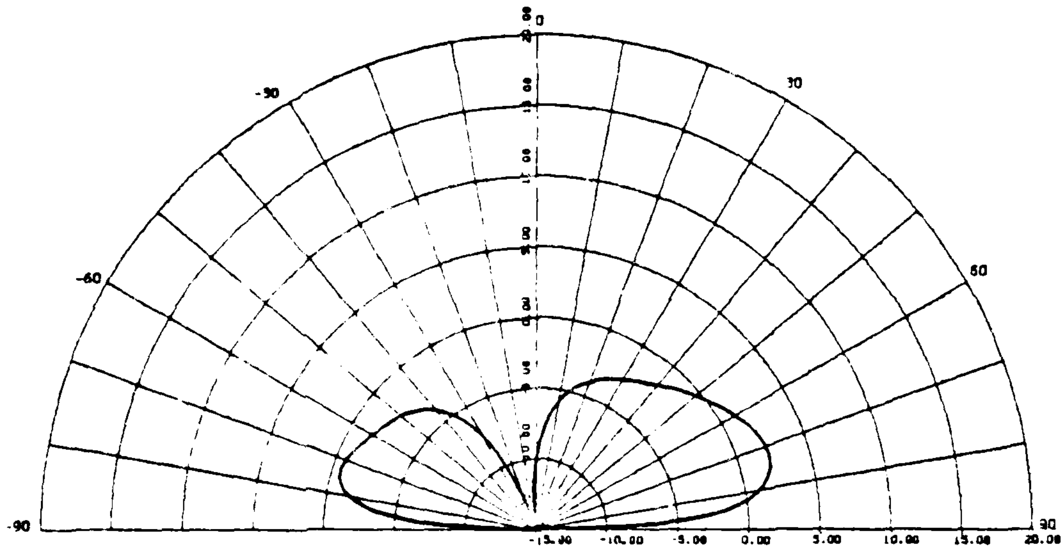
MRC-109 / PHI / THETA=70

PASTORAL / JEEP & TALA / 50 MHZ



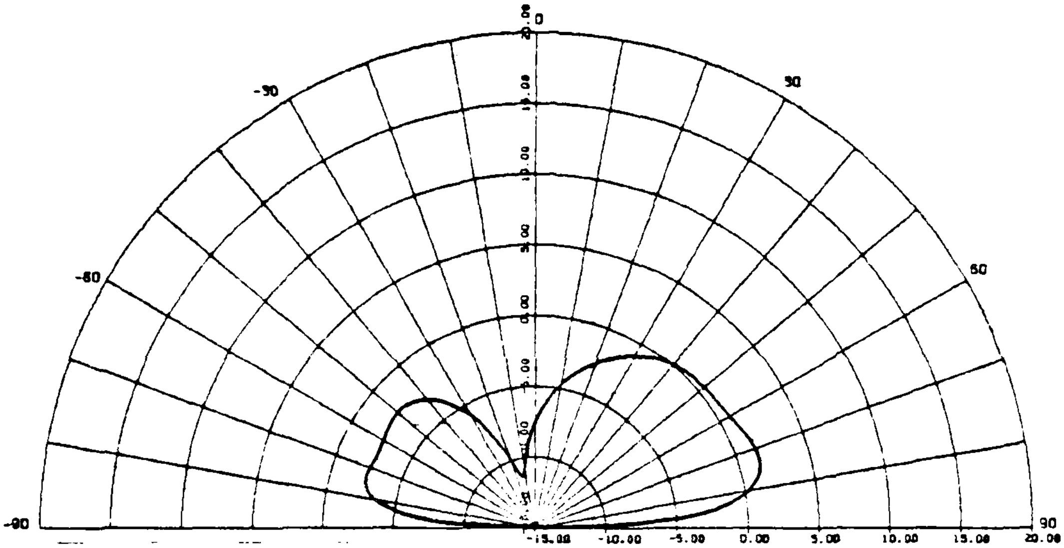
MAC-109 / THETA / PHI=90

PASTORAL / JEEP & TALA / 50 MHZ



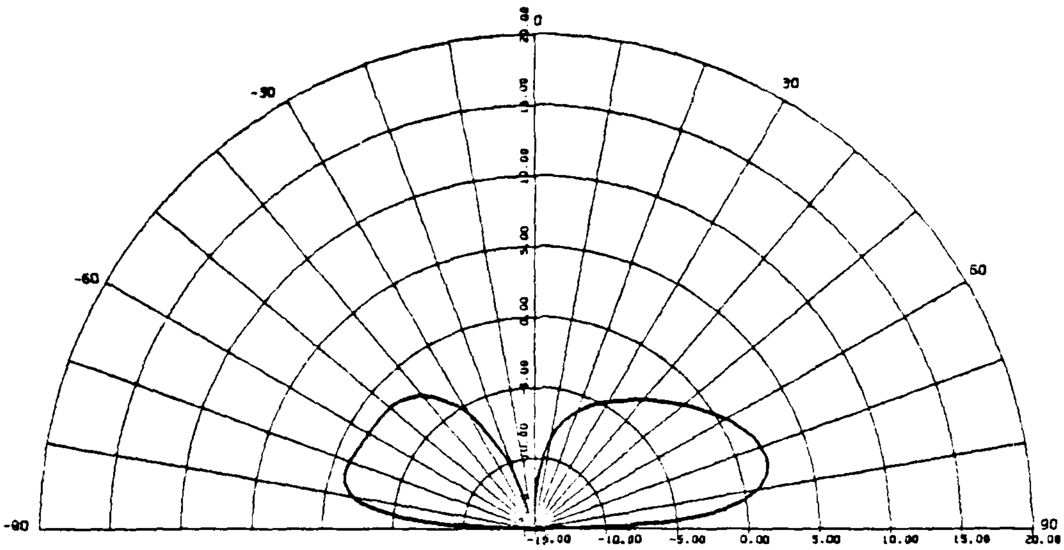
MAC-109 / THETA / PHI=180

PASTORAL / JEEP & TALA / 50 MHZ



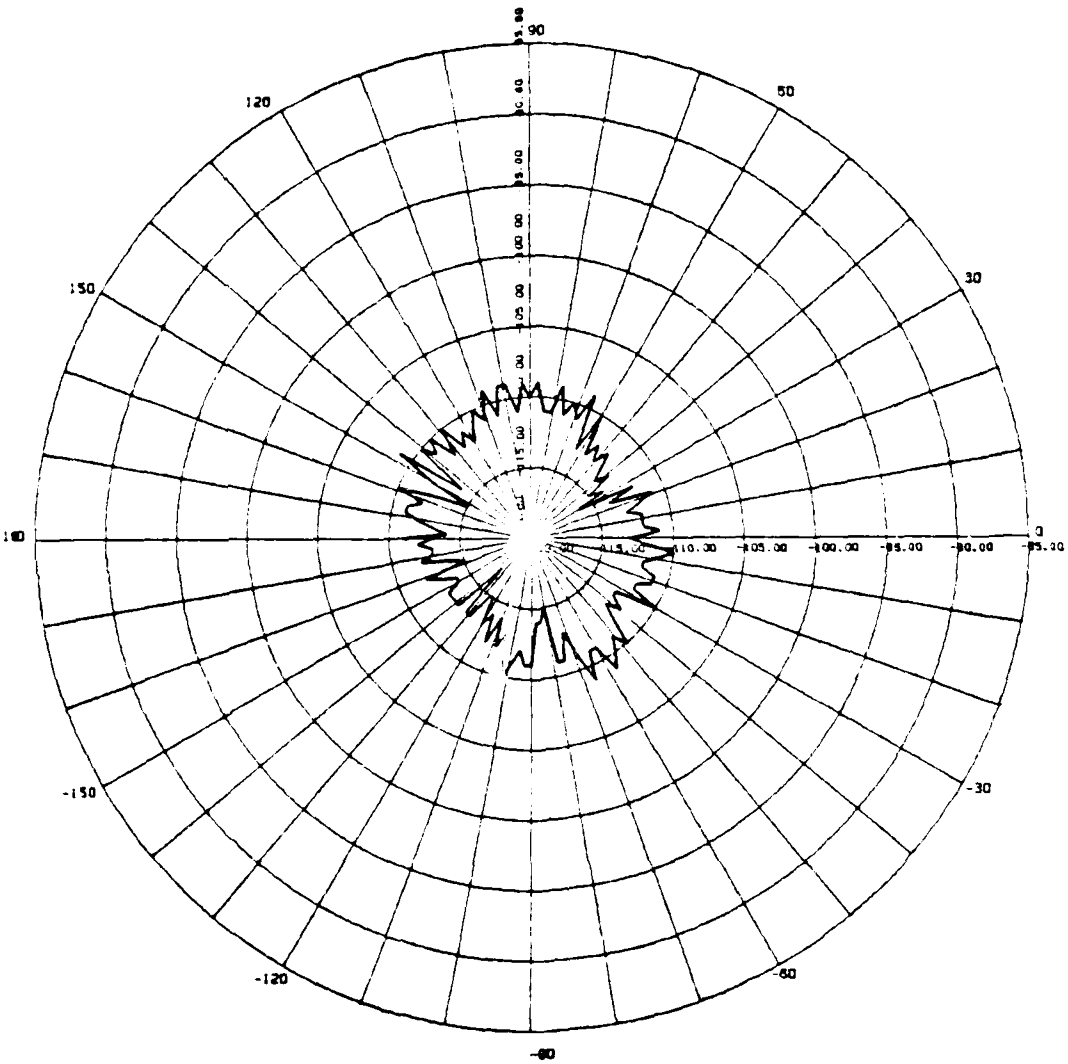
MAC-109 / THETA / PHI=120

PASTORAL / JEEP & TALA / 50 MHZ



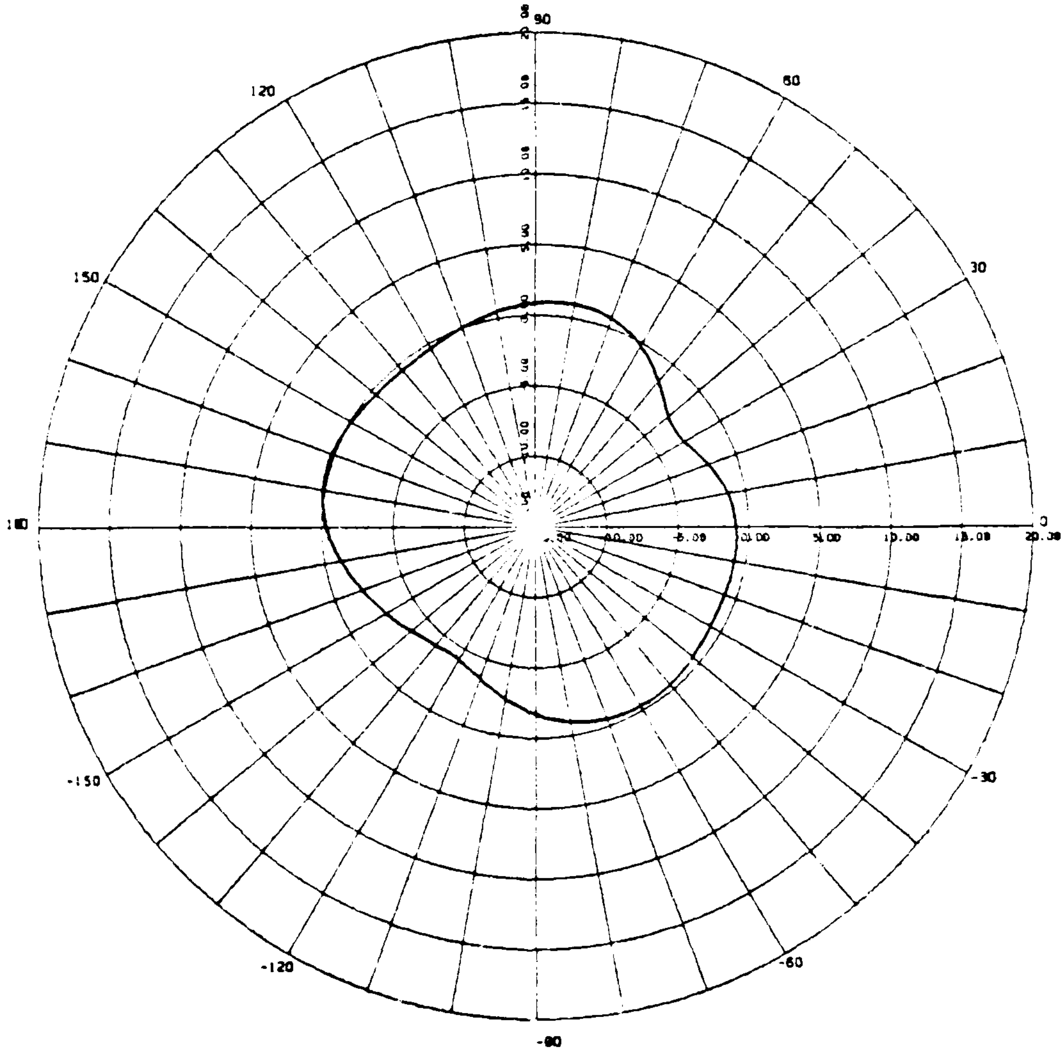
MAC-109 / PHI / THETA=90

PASTORAL / JEEP & TALA / 75 MHZ



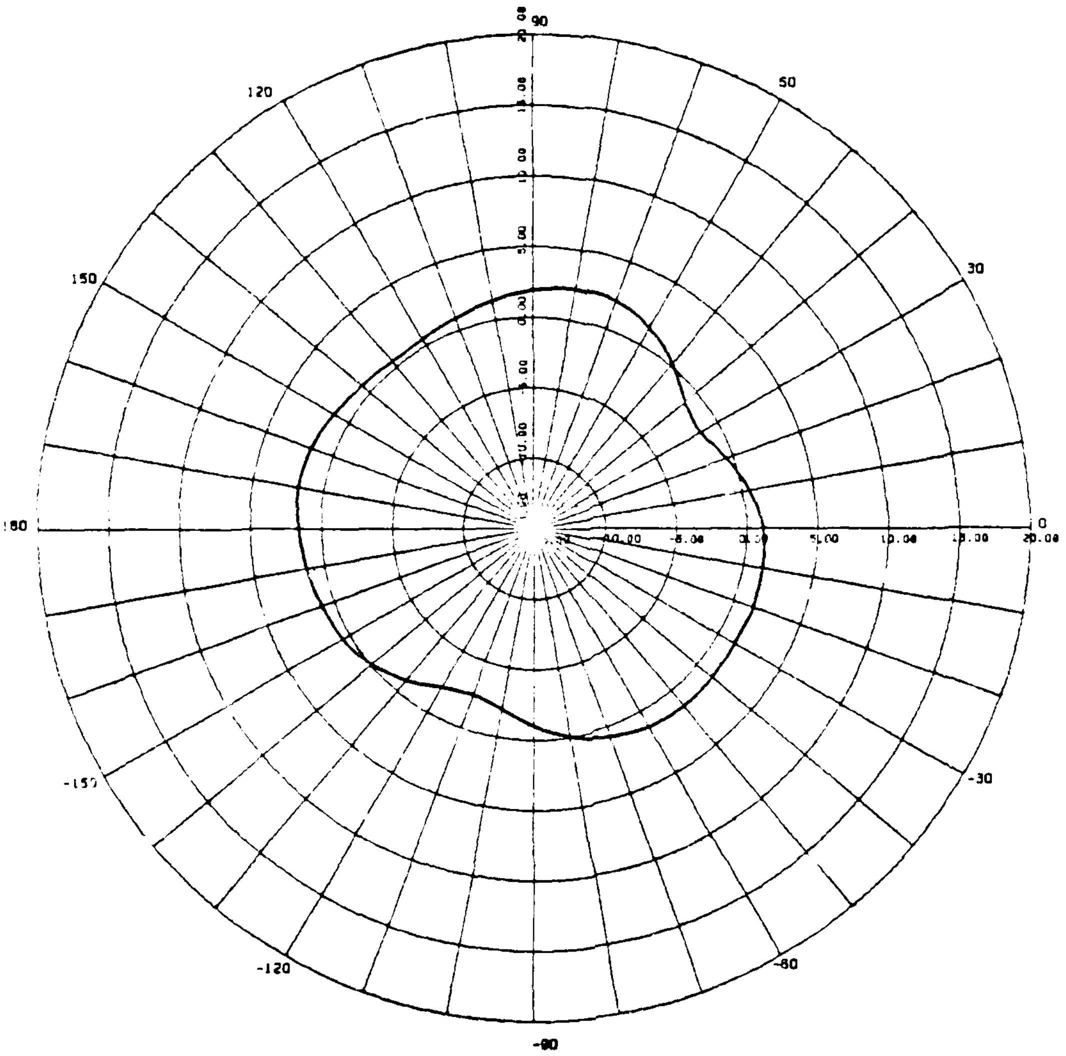
MAC-109 / PHI / THETA=80

PASTORAL / JEEP & TALA / 75 MHZ



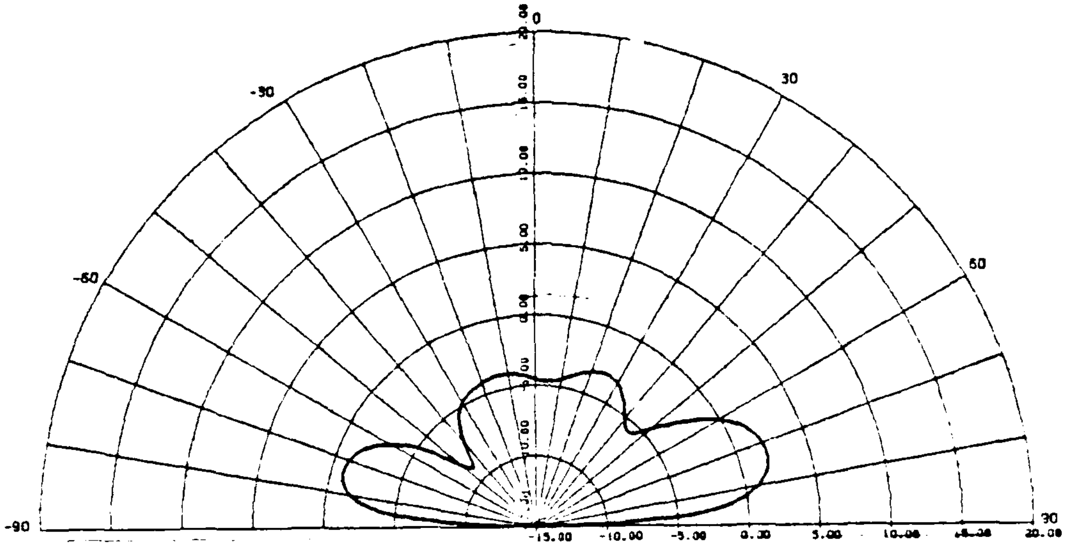
MAC-108 / PHI / THETA=70

PASTORAL / JEEP & TALA / 75 MHZ



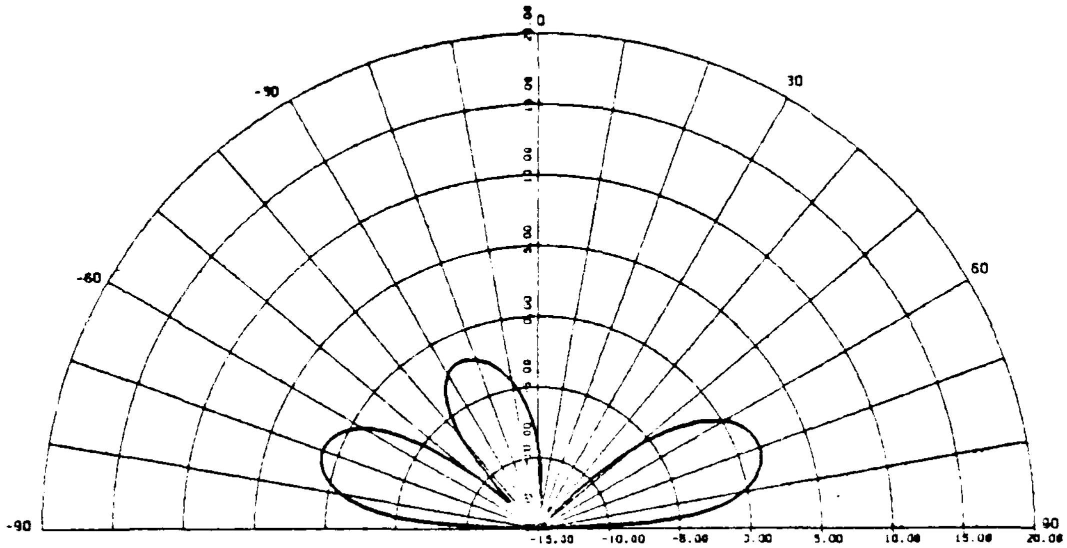
MRC-103 / THETA / PHI=90

PASTORAL / JEEP & TRLR / 75 MHZ



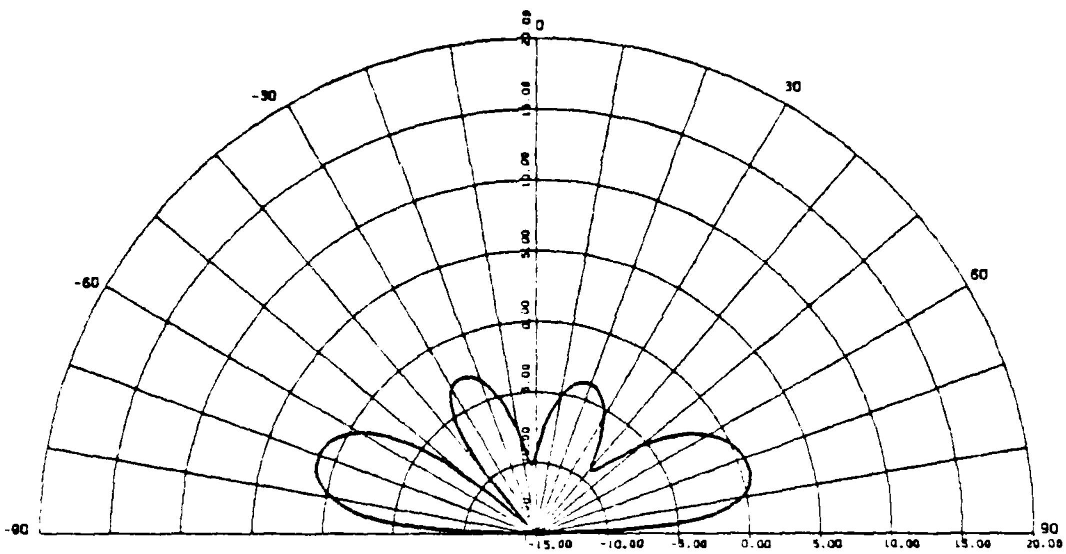
MAC-109 / THETA / PHI=180

PASTORAL / JEEP & TALA / 75 MHZ



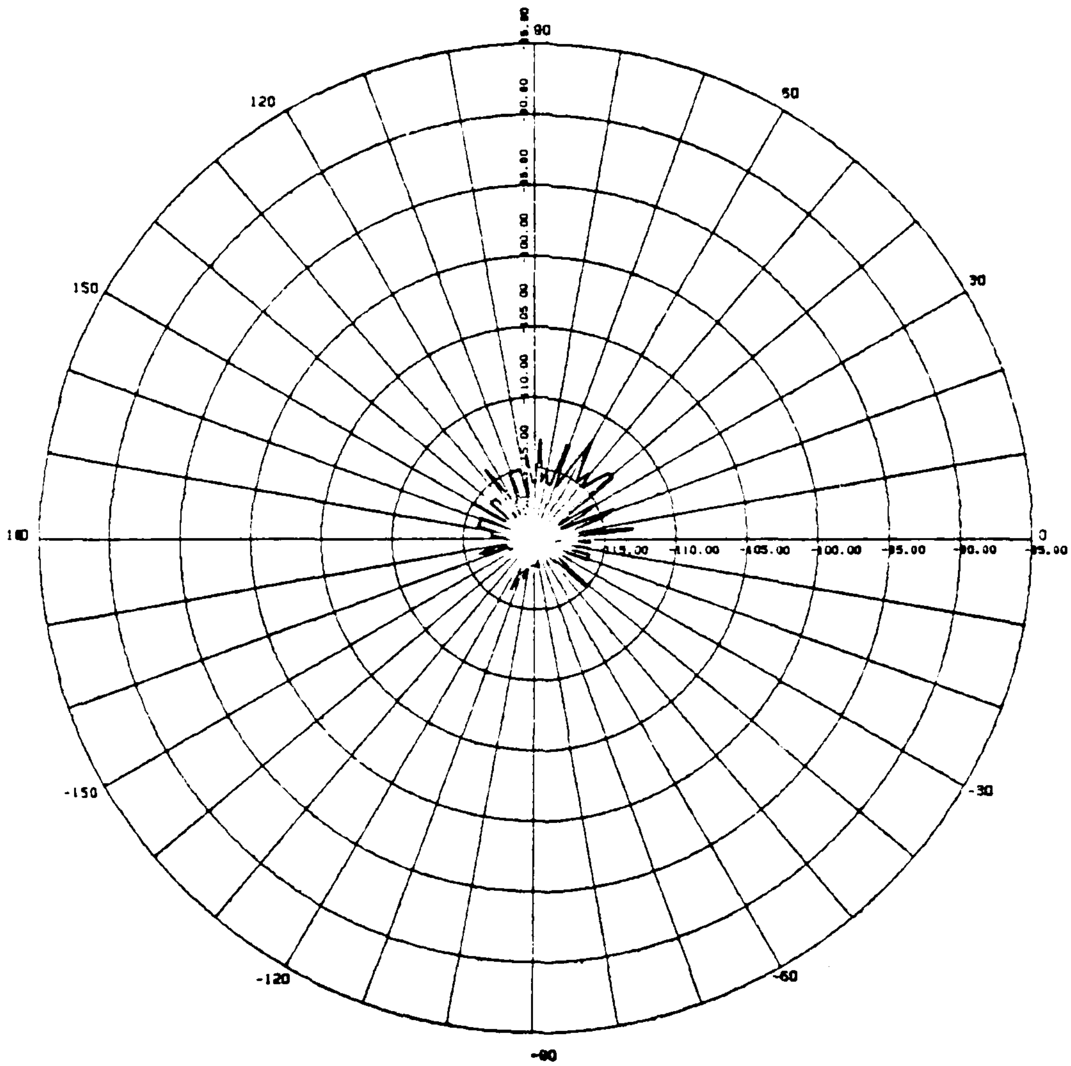
MAC-109 / THETA / PHI=120

PASTORAL / JEEP & TRLR / 75 MHZ



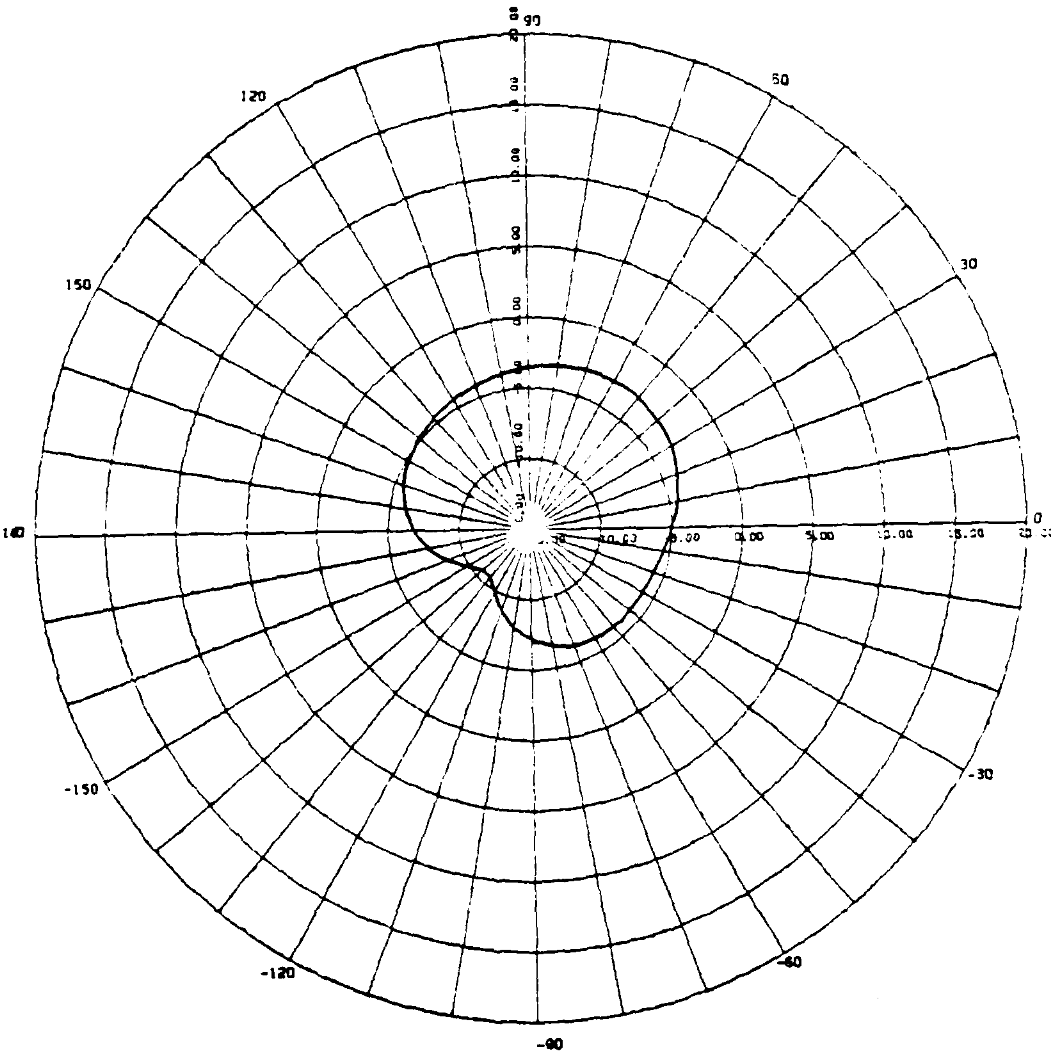
MAC-109 / PHI / THETA=90

SNOW / BASIC / 30 MHZ



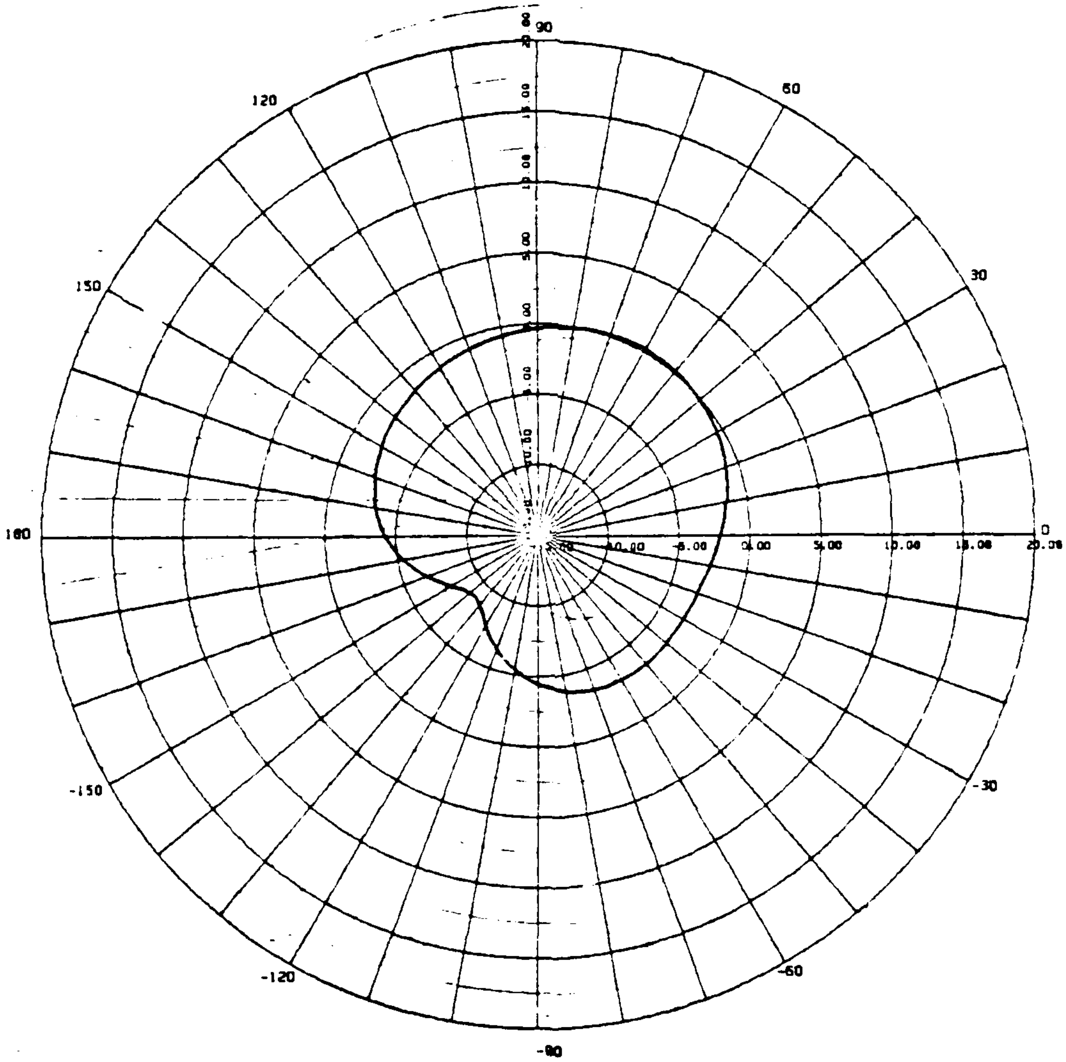
MRC-109 / PHI / THETA= 80

SNOW / BASIC / 30 MHZ



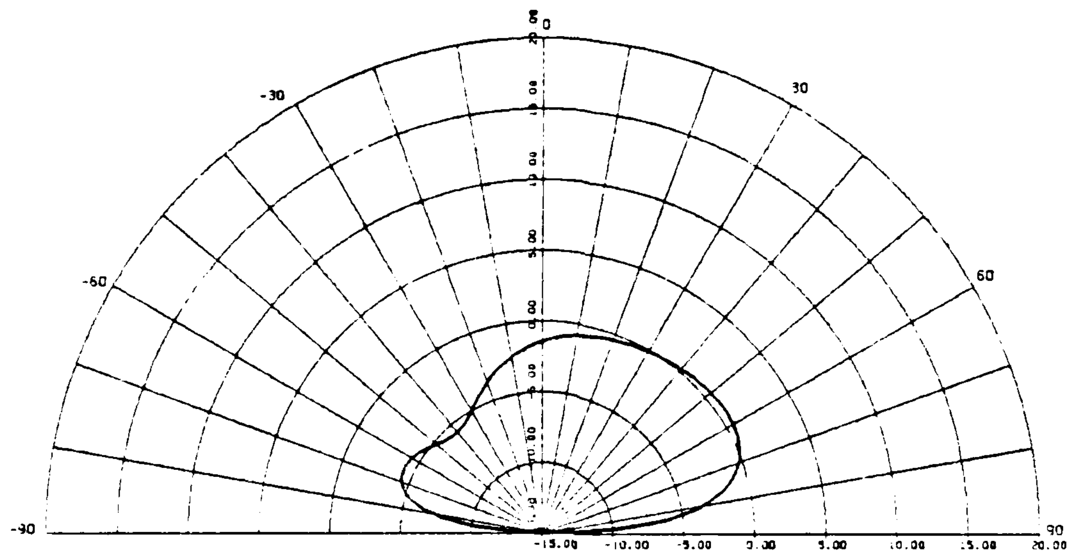
MAC-109 / PHI / THETA= 70

SNOW / BASIC / 30 MHZ



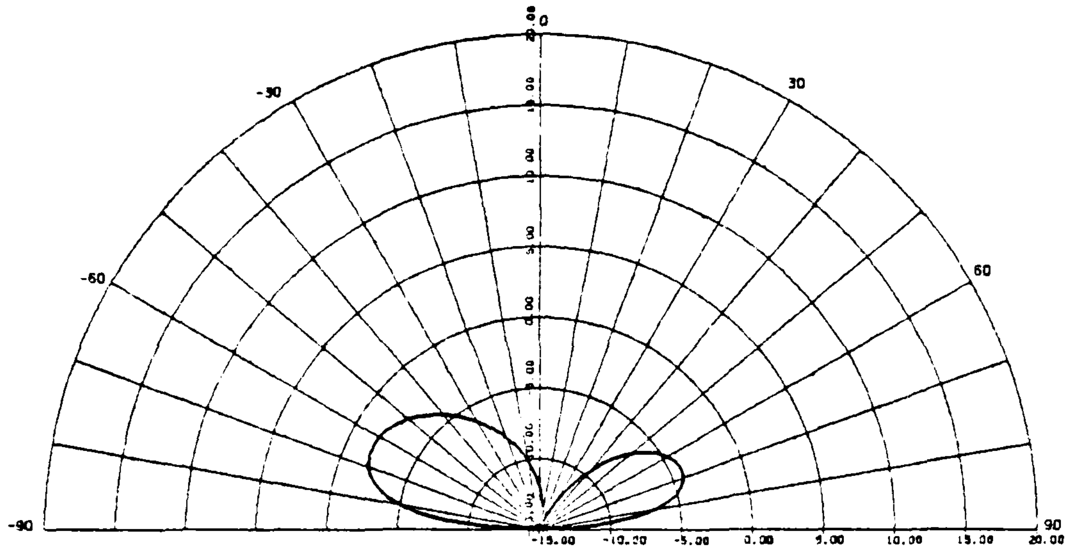
MRC-103 / THETA / PHI = 30

SNOW / BASIC / 30 MHZ



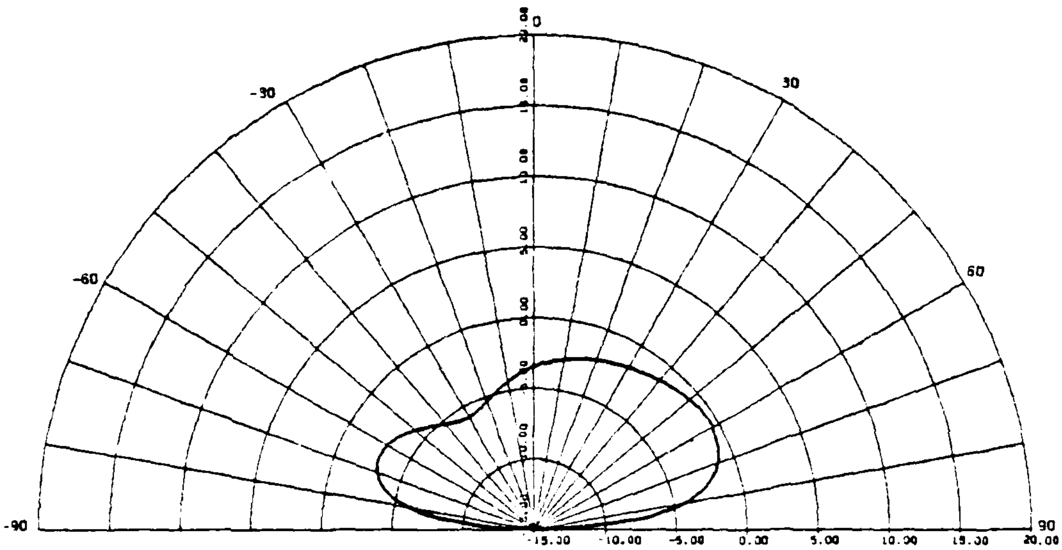
MAC-109 / THETA / PHI = 180

SNOW / BASIC / 30 MHZ



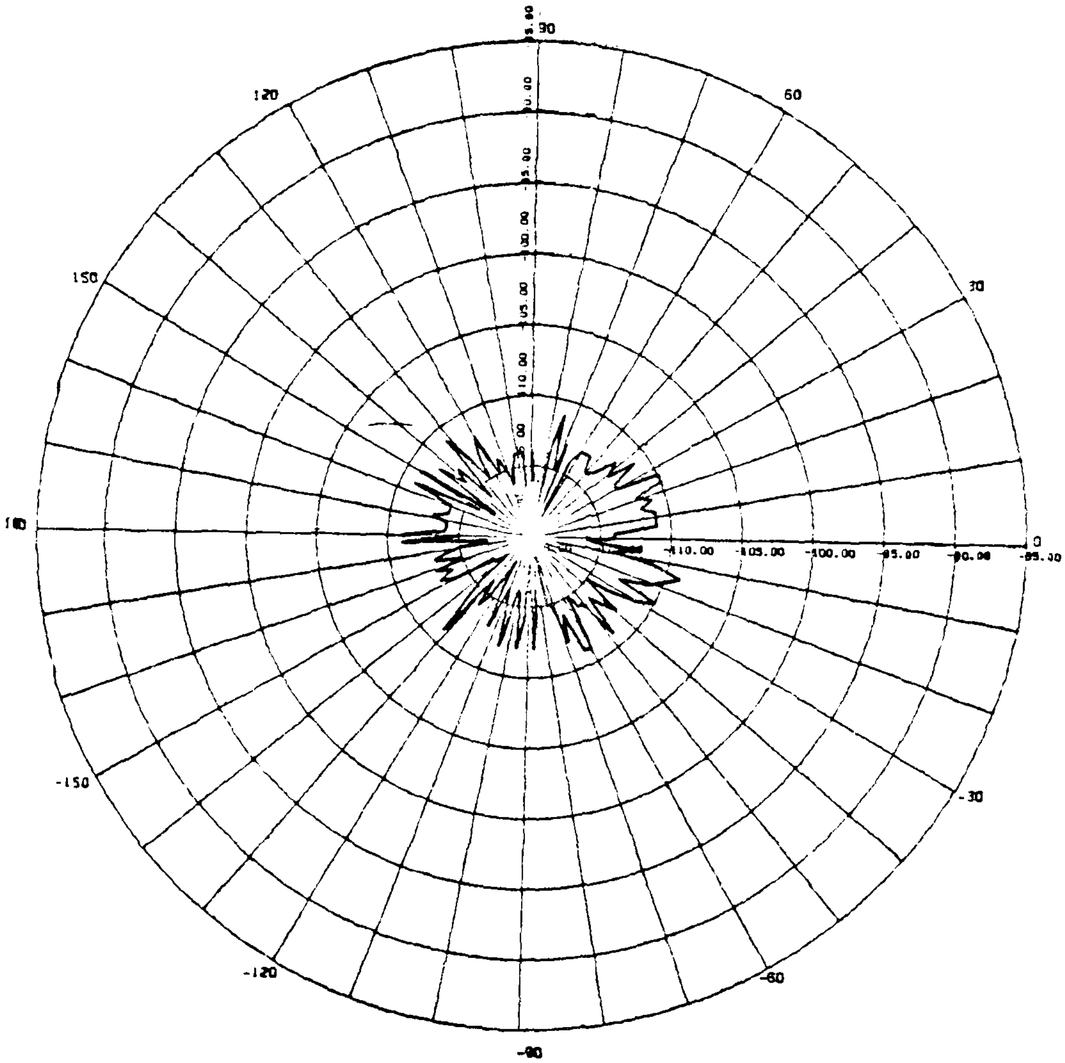
MAC-109 / THETA / PHI = 120

SNOW / BASIC / 30 MHZ



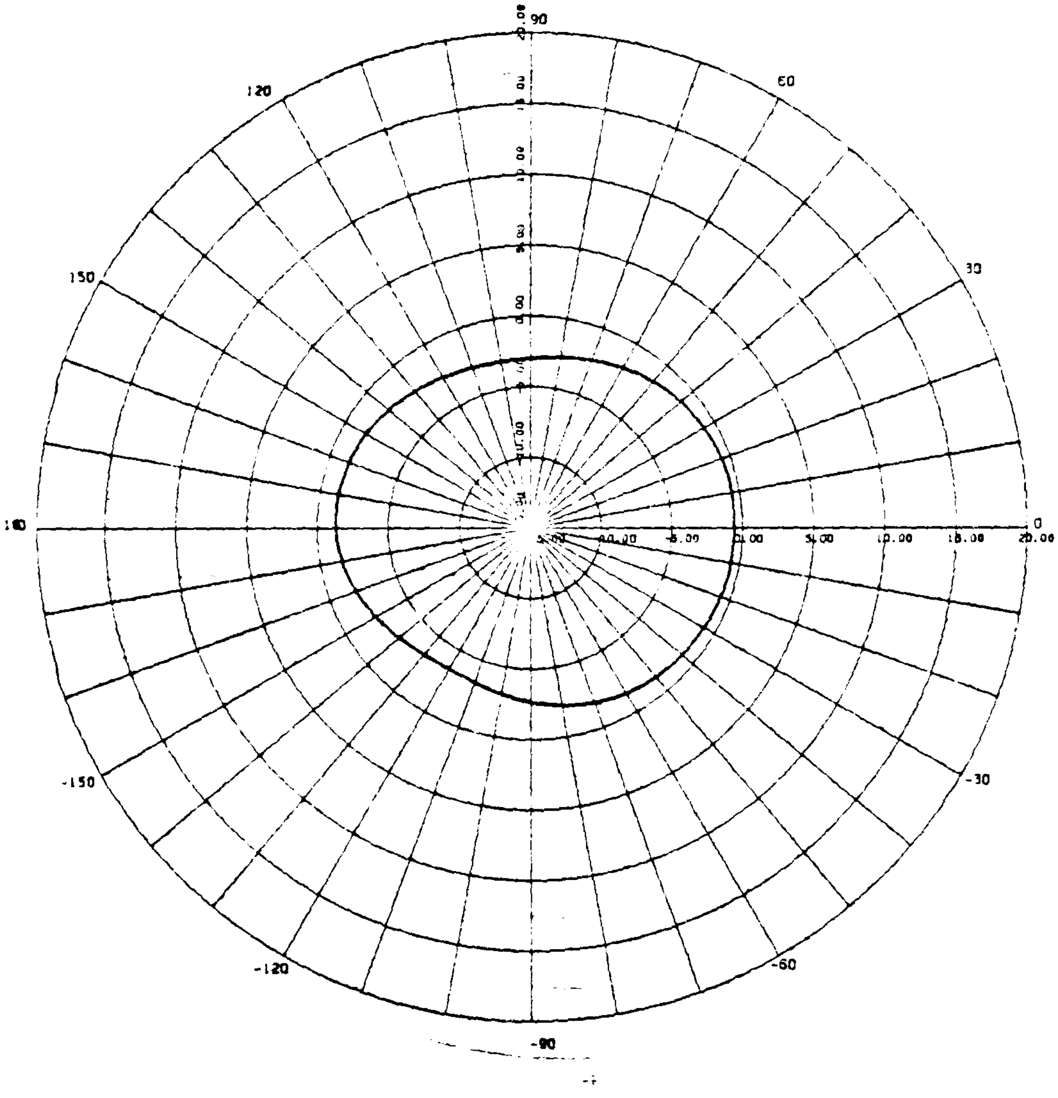
MAC-103 / PHI / THETA=90

SNOW / BASIC / 41 MHZ



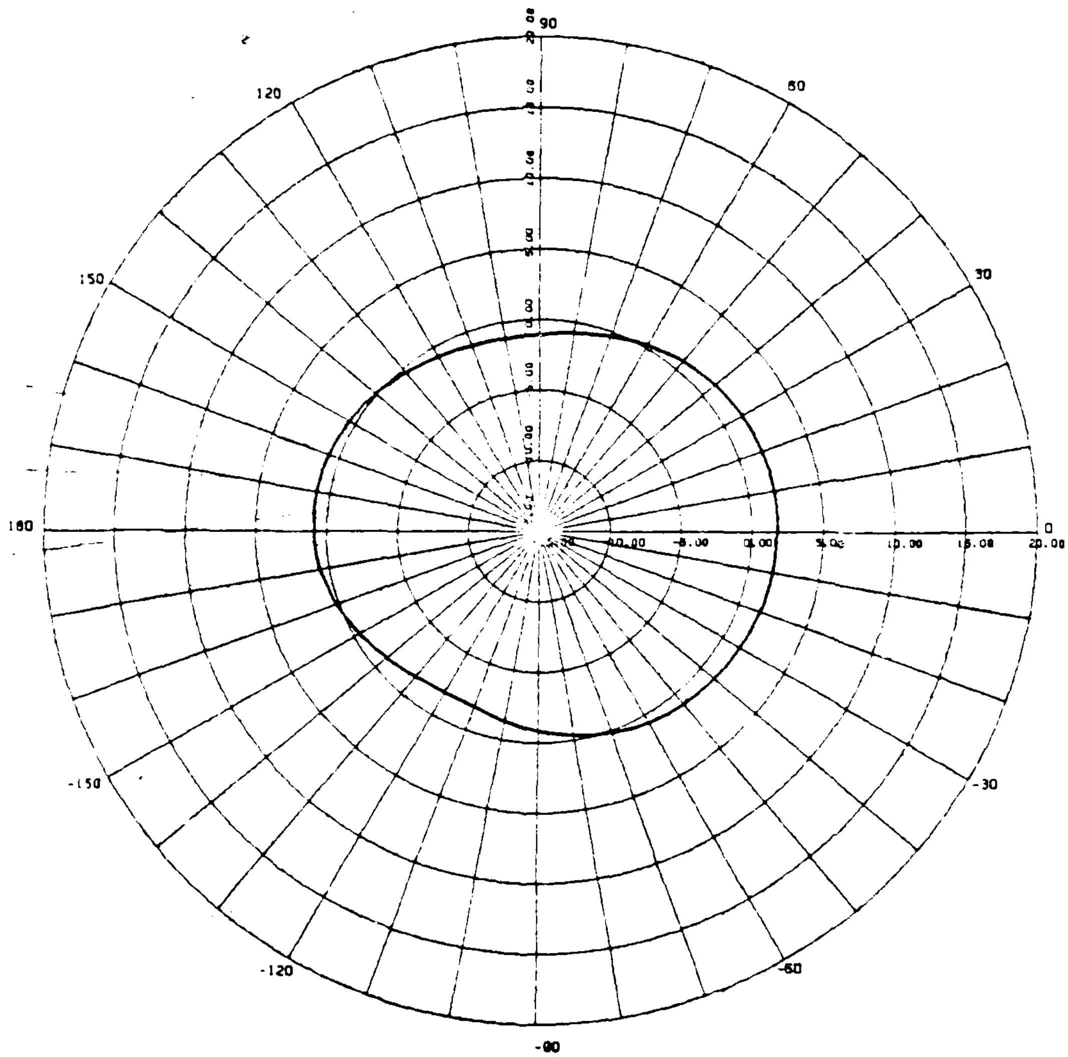
MRC-109 / PHI / THETA= 80

SNOW / BASIC / 41 MHZ



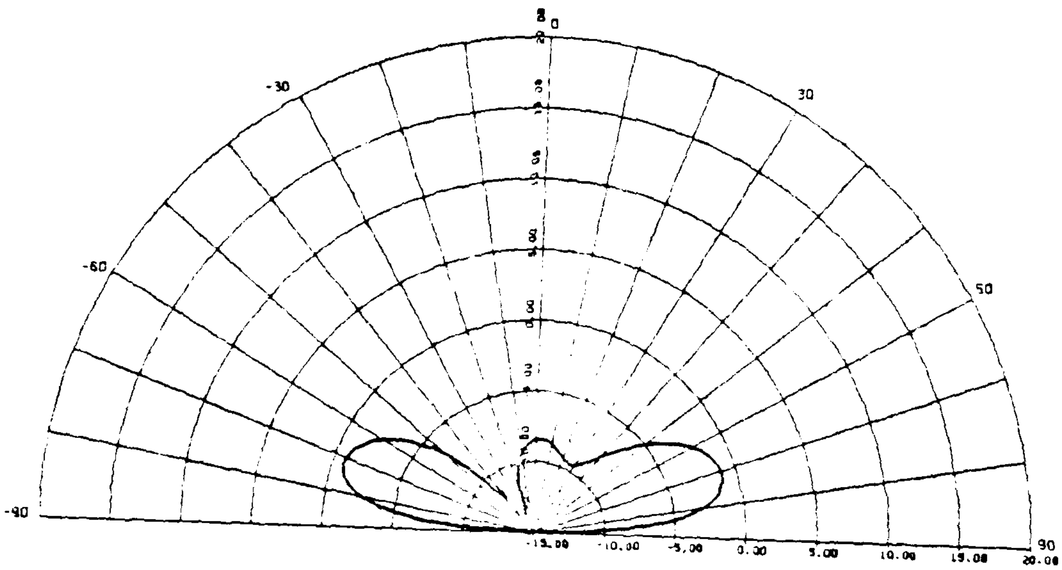
MPC-103 / PHI / THETA= 70

SNOW / BASIC / 41 MHZ



MAC-109 / THETA / PHI = 90

SNOW / BASIC / 41 MHZ



AD-A097 386 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 9/1
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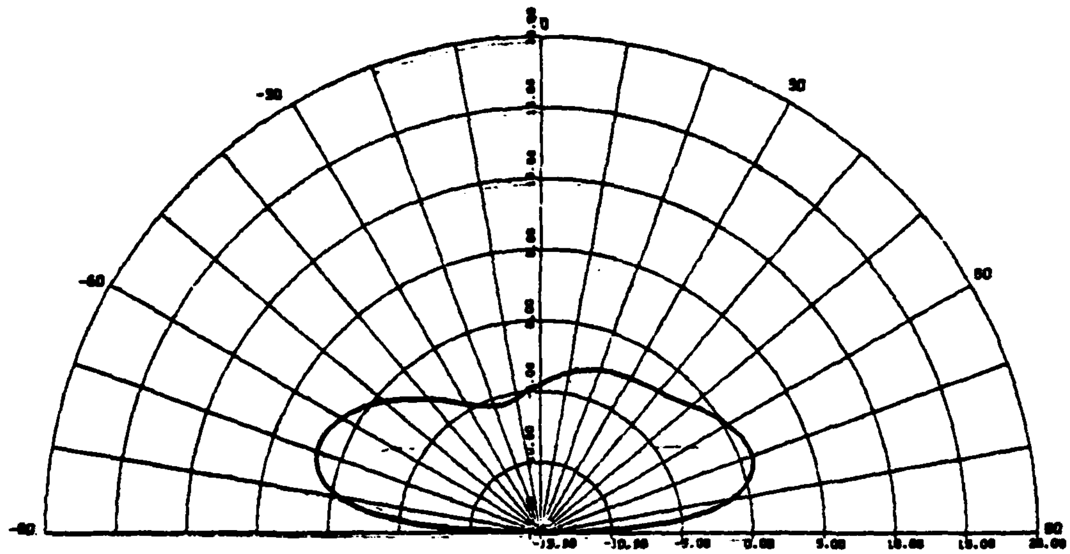
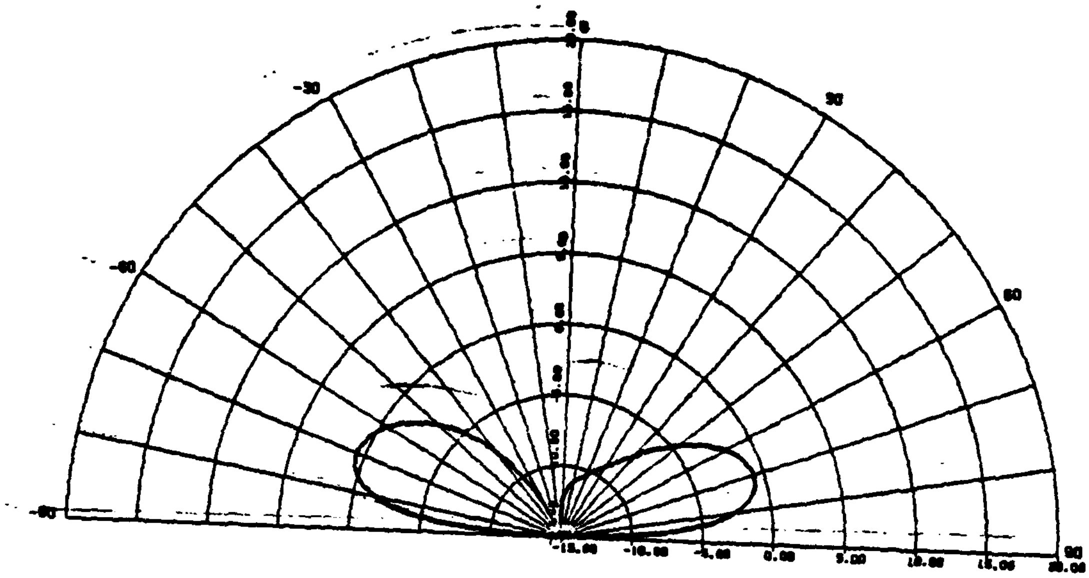
MRC-109 / THETA / PHI = 180

SNOW / BASIC / 41 MHZ



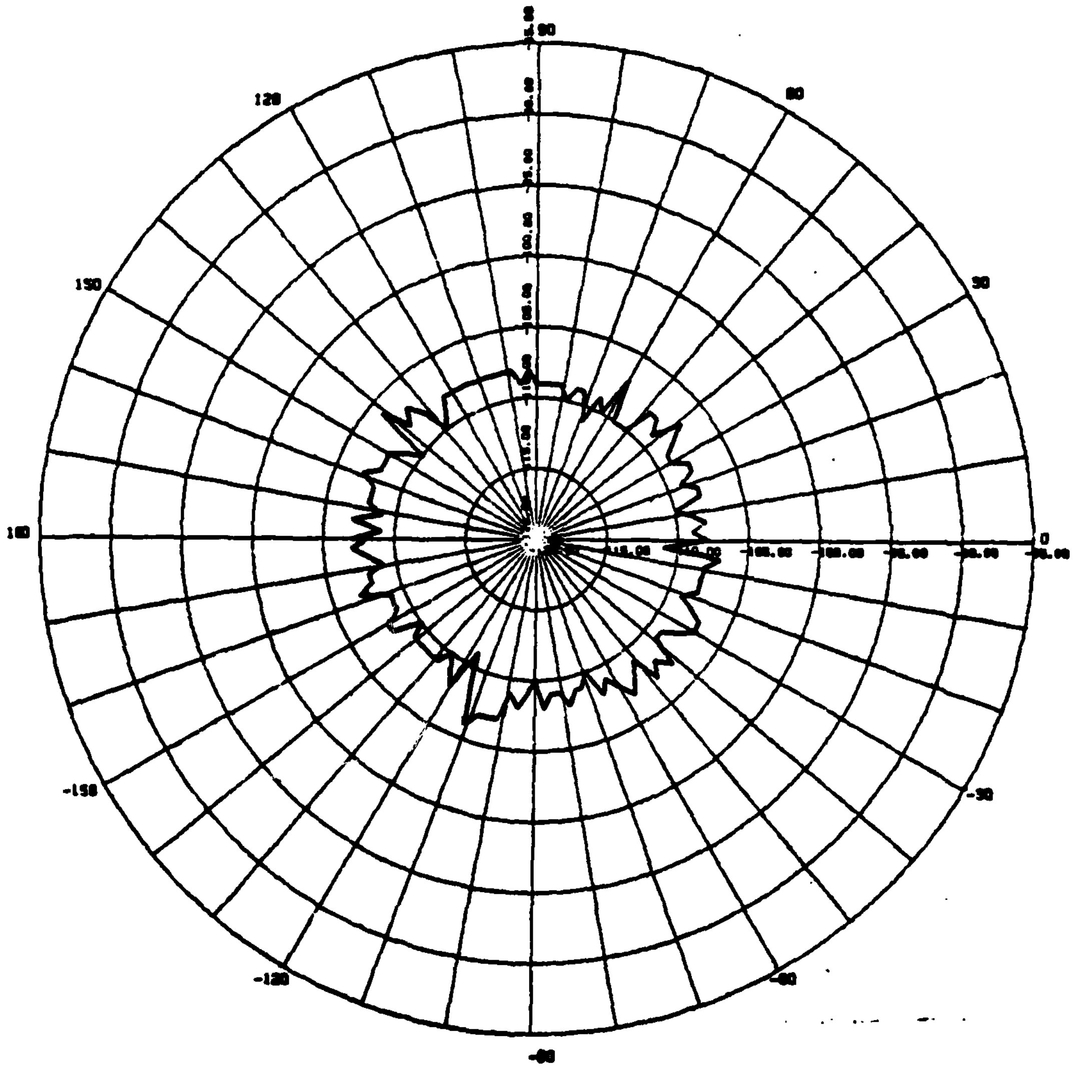
MAC-109 / THETA / PHI = 120

SNOW / BASIC / 41 MHZ



MAC-109 / PHI / THETA=90

SNOW / BASIC / 50 MHZ



MAC-109 / PHI / THETA= 80

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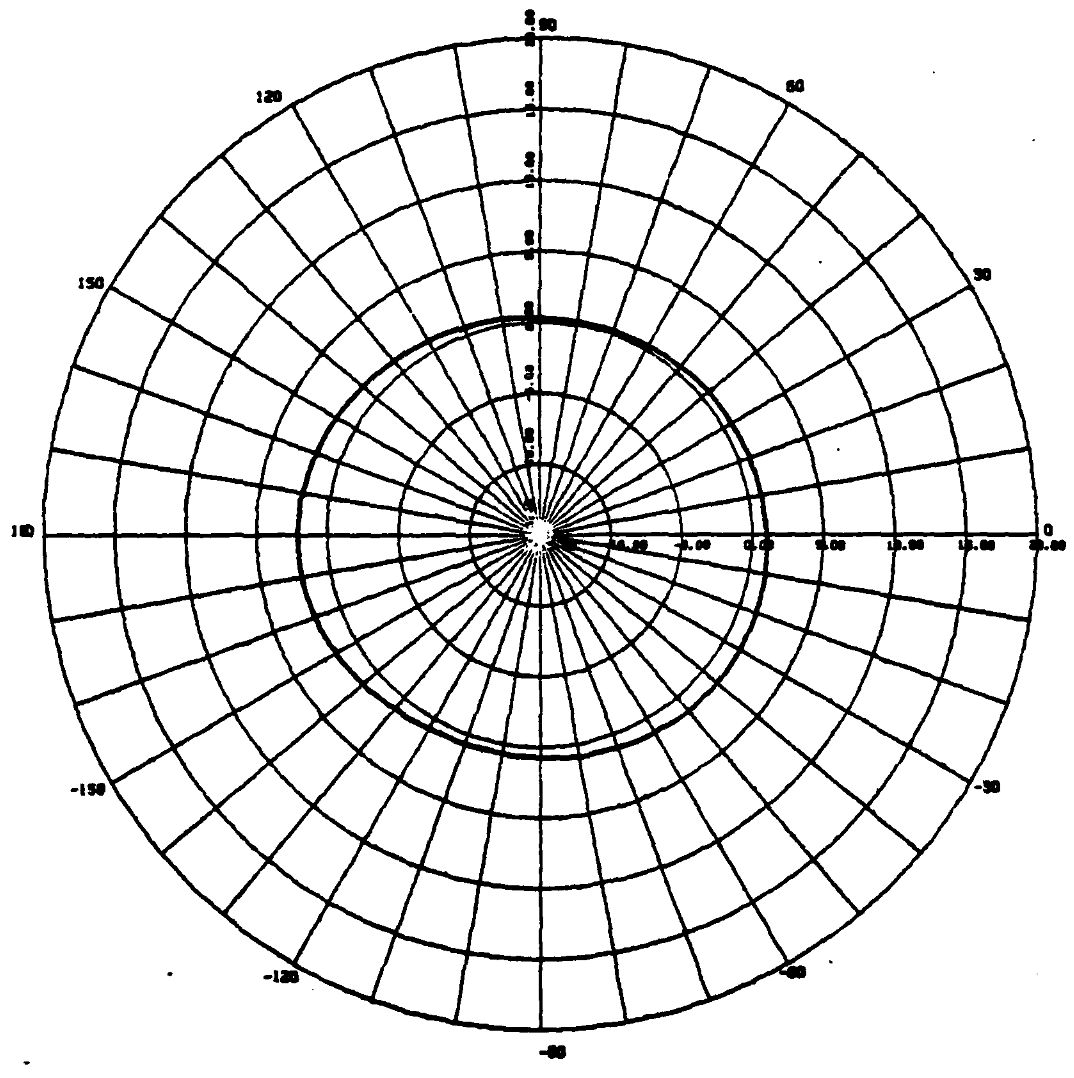
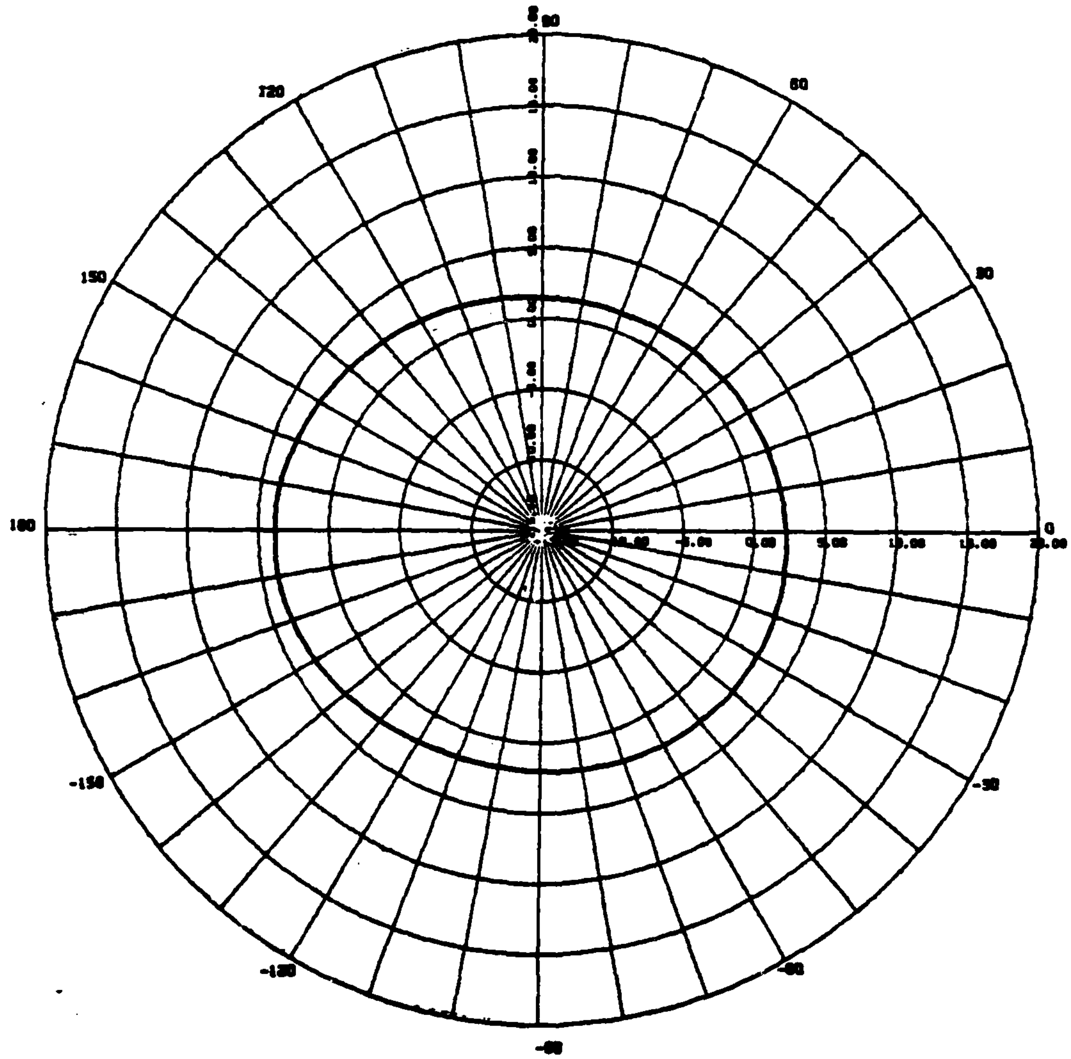


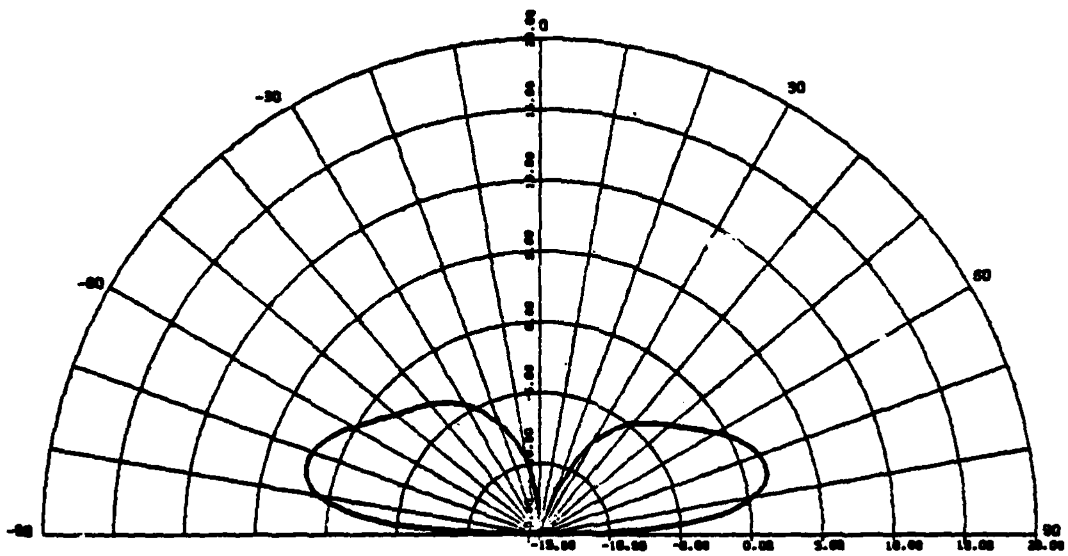
MAC-109 / PHI / THETA= 70

SNOW / BASIC / 50 MHZ



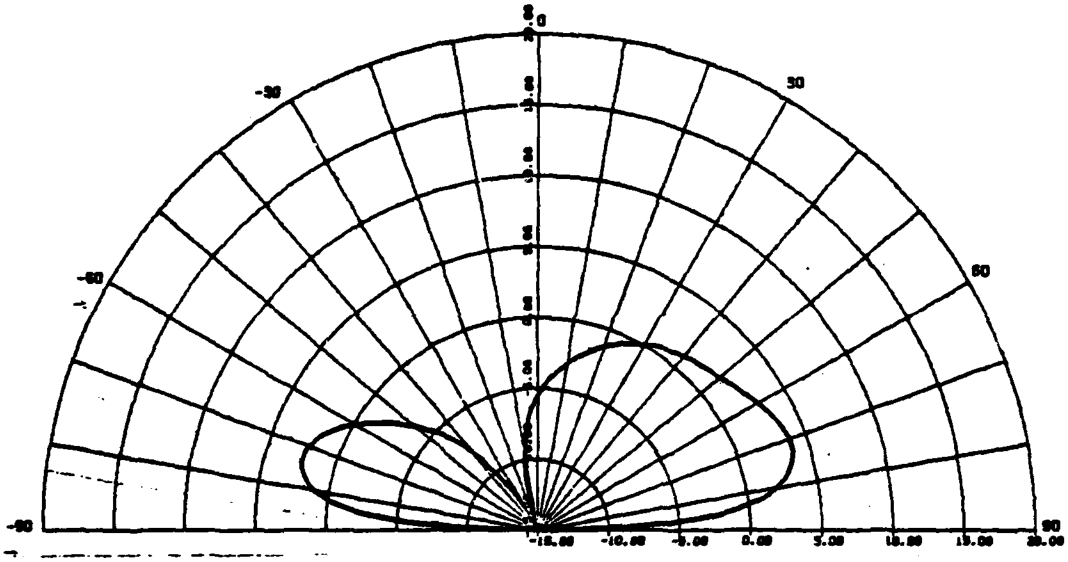
MAC-109 / THETA / PHI = 90

SNOW / BASIC / 50 MHZ



MAC-109 / THETA / PHI = 180

SNOW / BASIC / 50 MHZ



MAC-109 / THETA / PHI = 120

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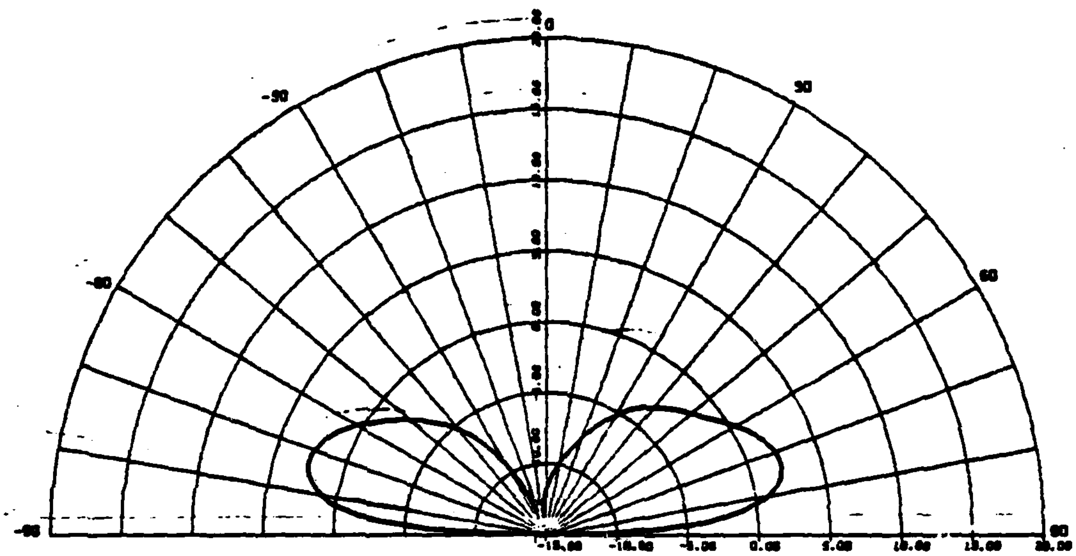
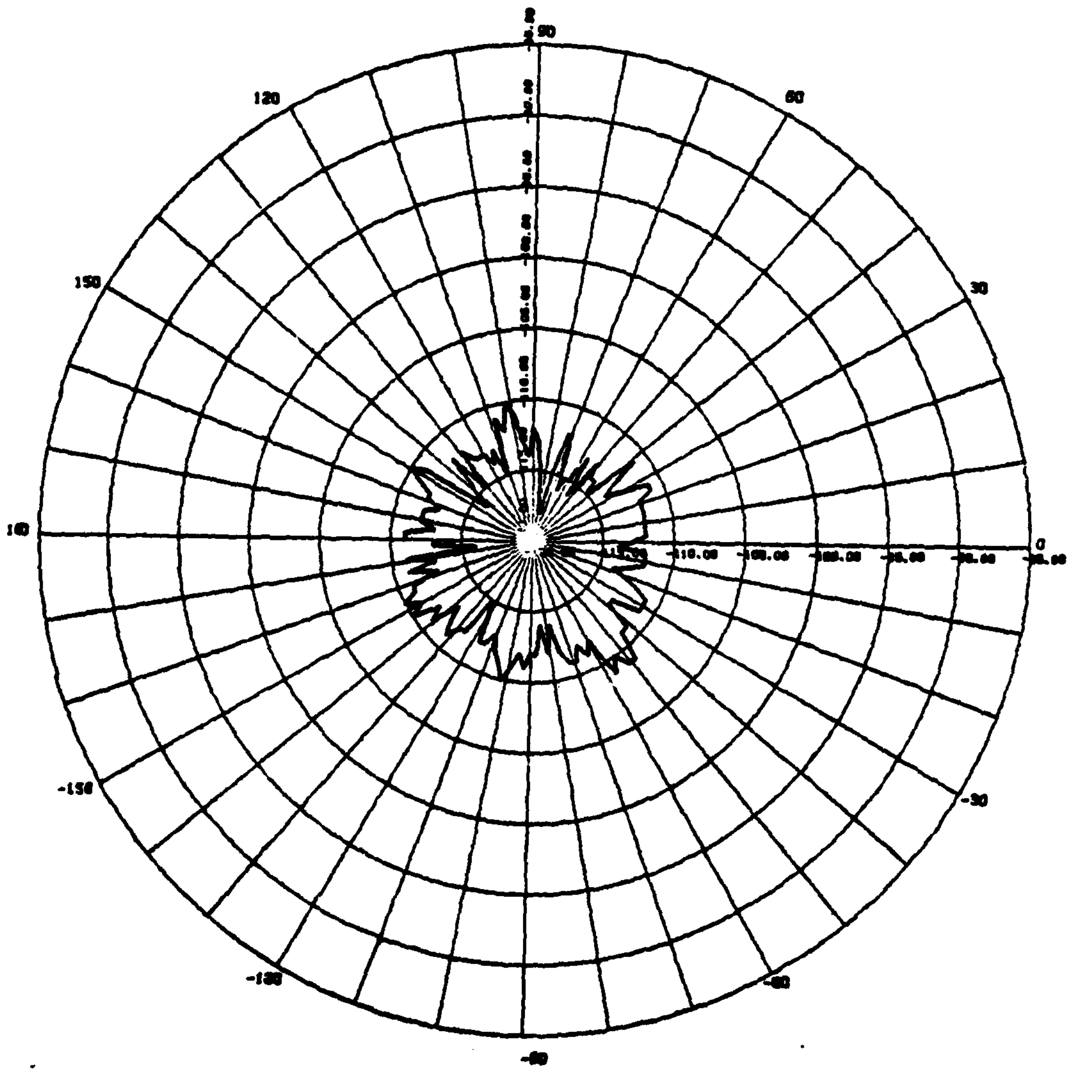


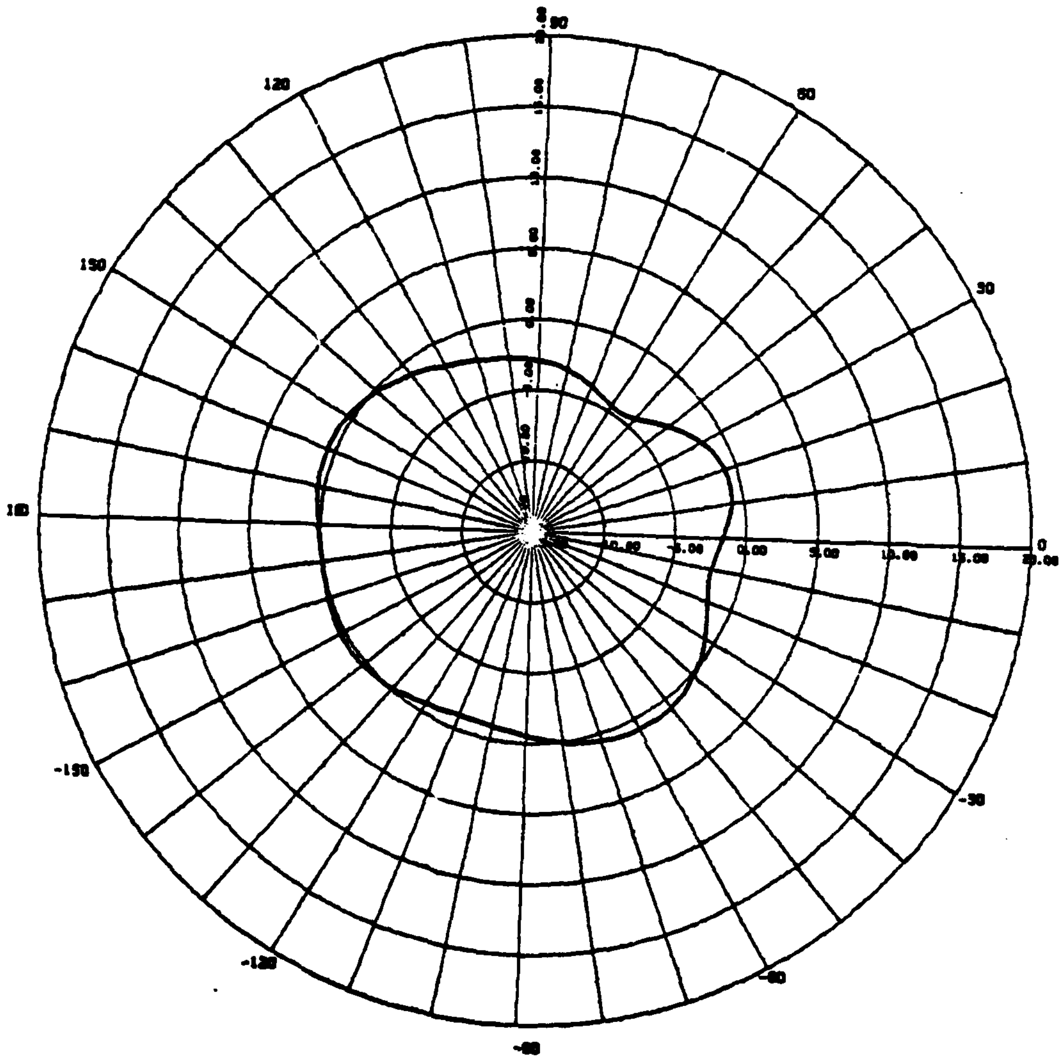
MAC-109 / PHI / THETA=90

SNOW / BASIC / 75 MHZ



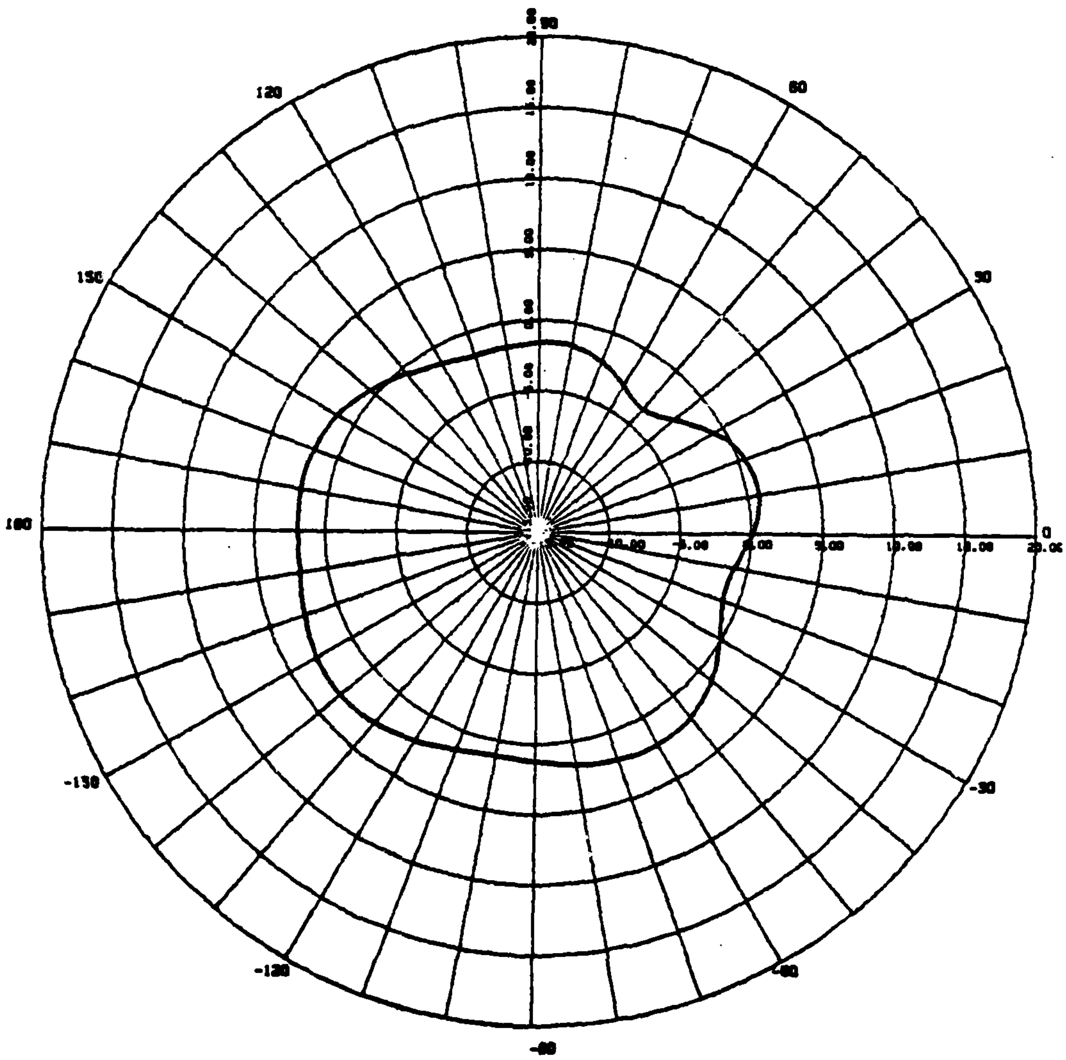
MAC-109 / PHI / THETA= 80

SNOW / BASIC / 75 MHZ



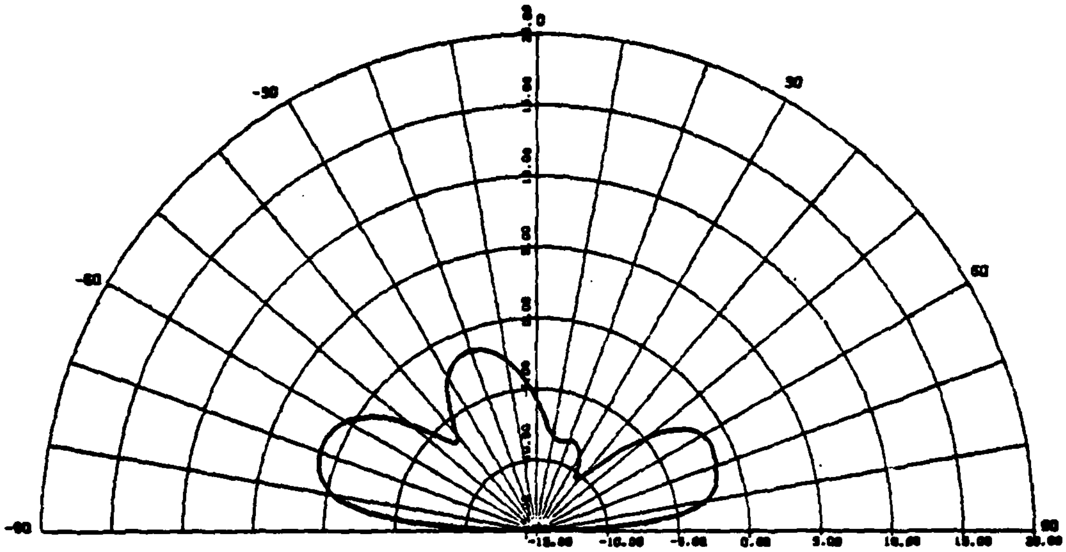
MAC-109 / PHI / THETA= 70

SNOW / BASIC / 75 MHZ



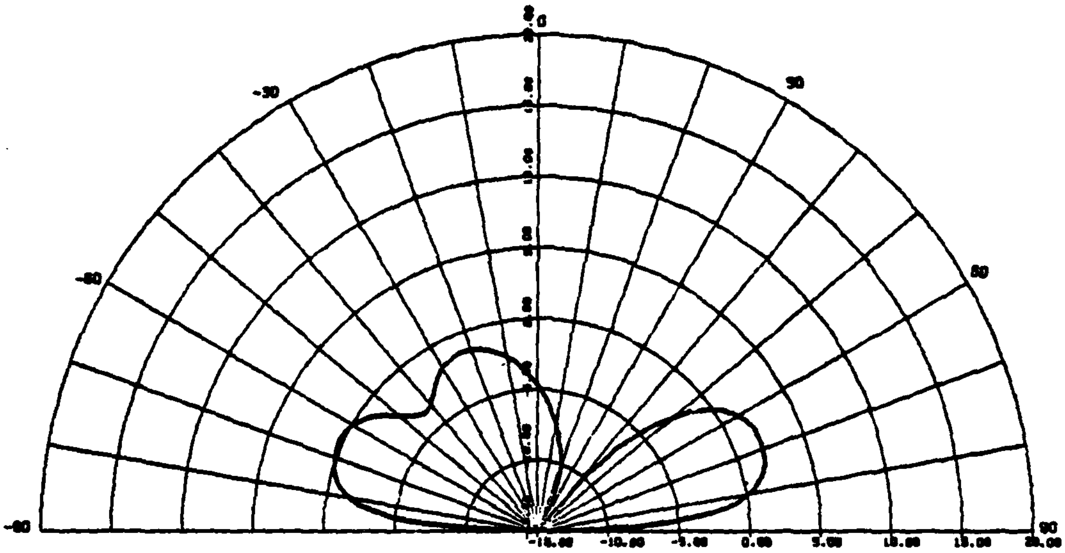
MAC-109 / THETA / PHI = 90

SNOW / BASIC / 75 MHZ



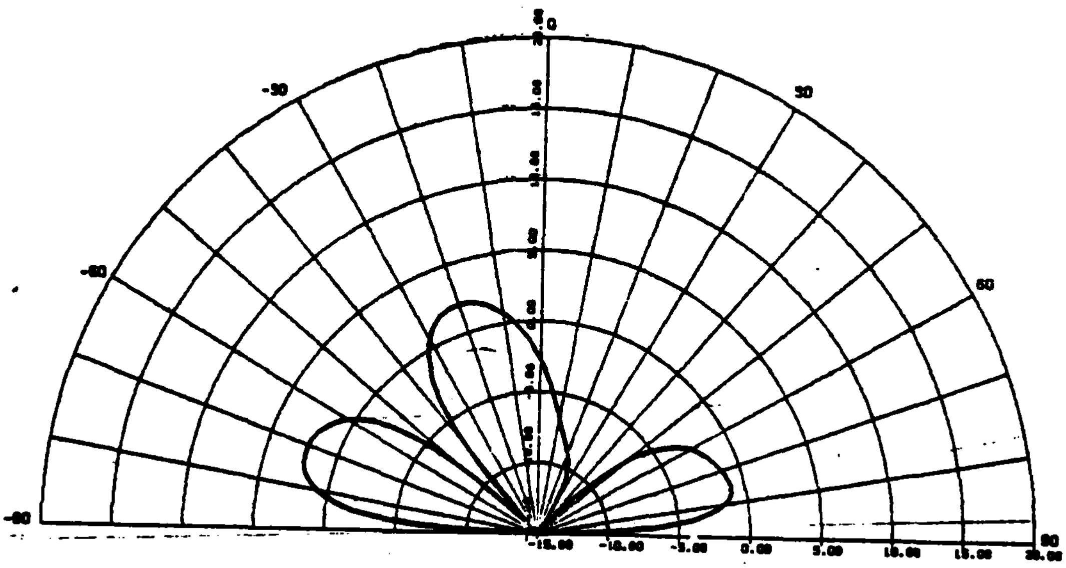
MAC-109 / THETA / PHI = 180

SNOW / BASIC / 75 MHZ



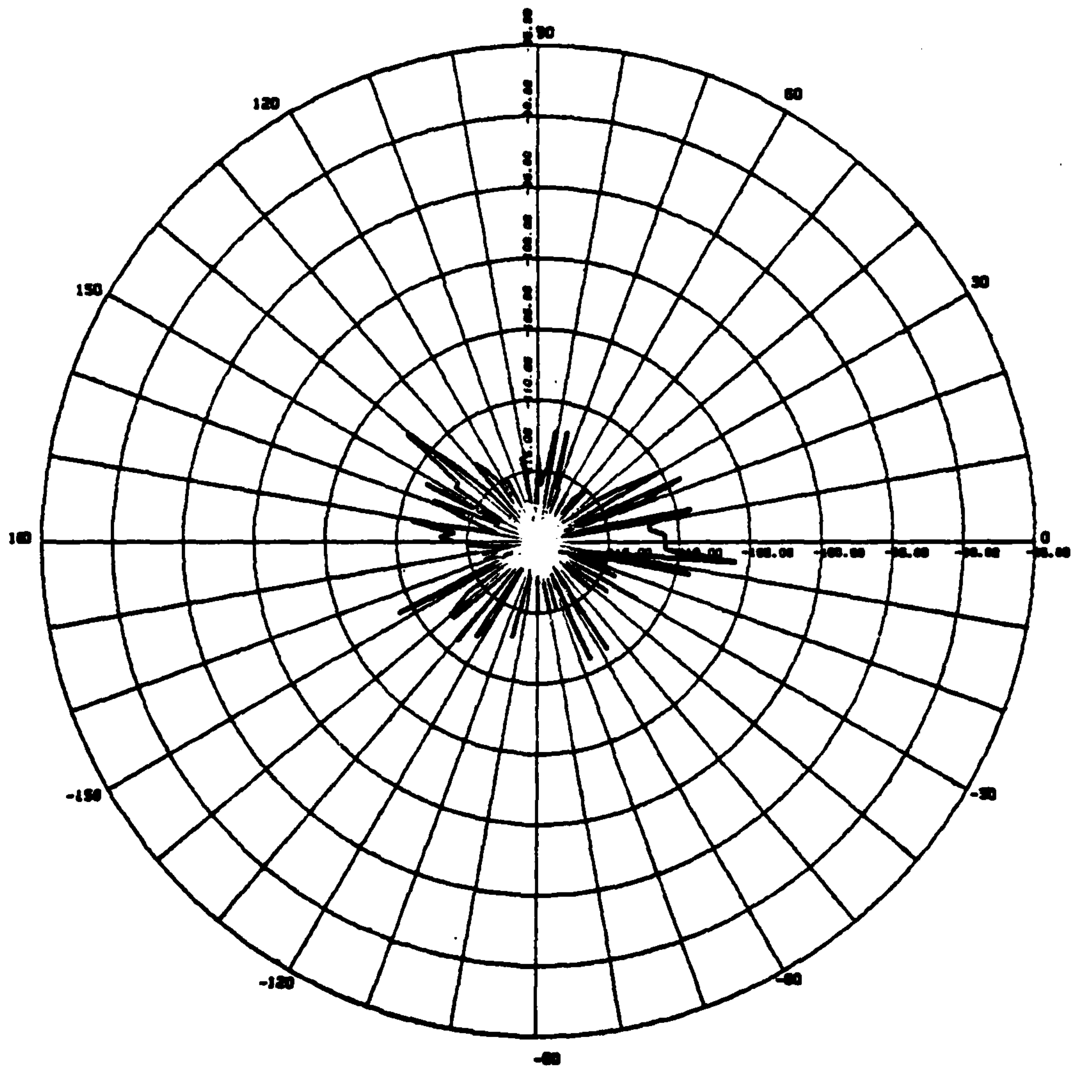
MAC-109 / THETA / PHI = 120

SNOW / BASIC / 75 MHZ



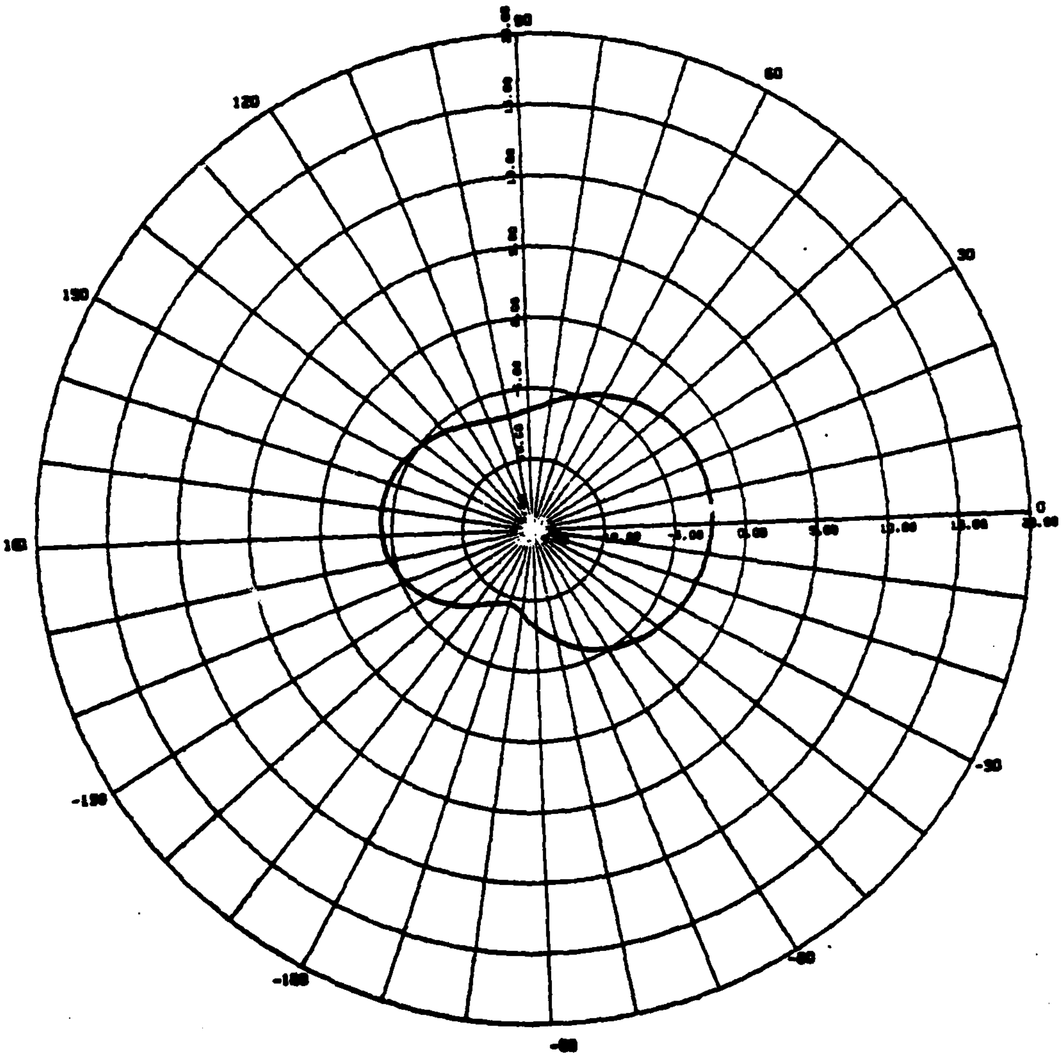
MRC-109 / PHI / THETA=90

SNOW / JEEP / 30 MHZ



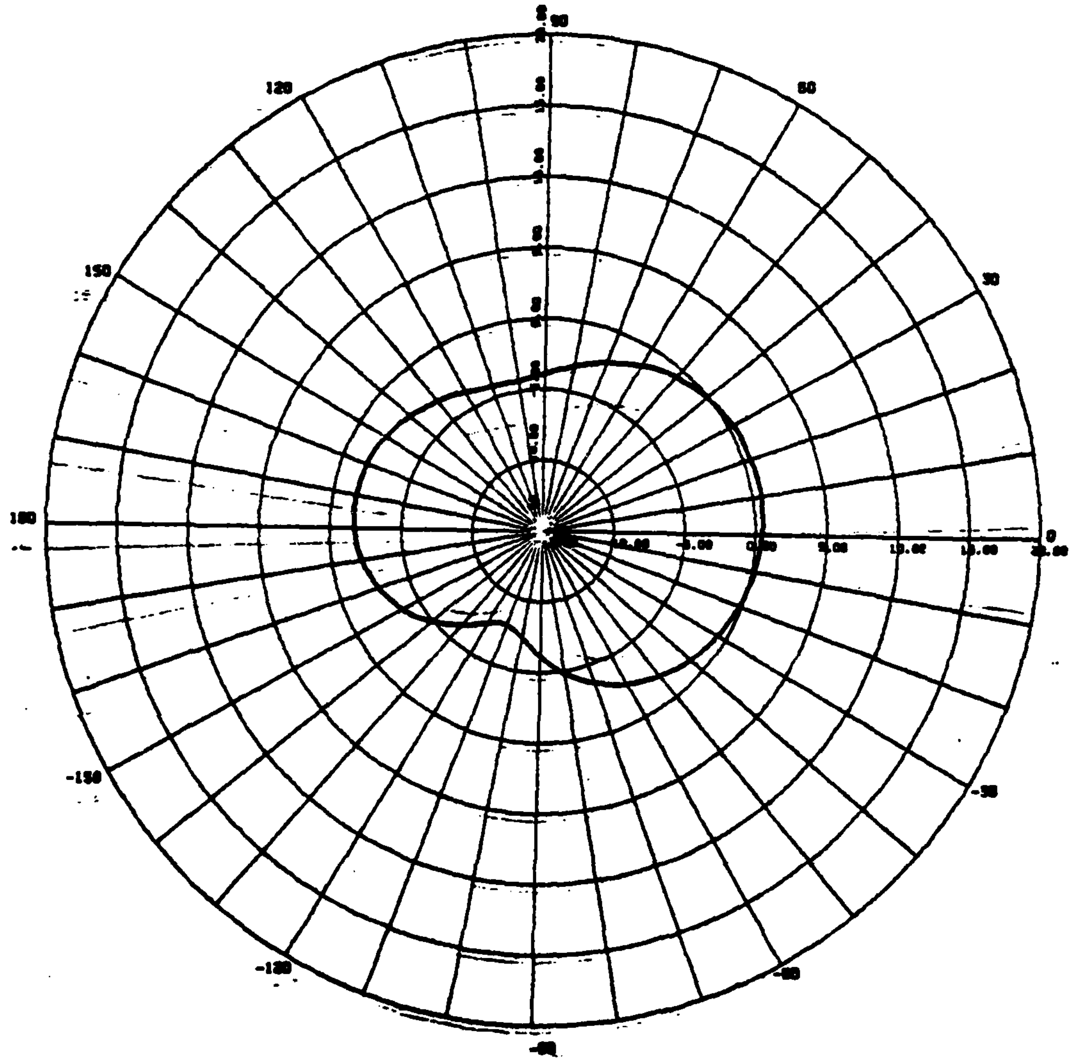
MAC-109 / PHI / THETA= 80

SNOW / JEEP / 30 MHZ



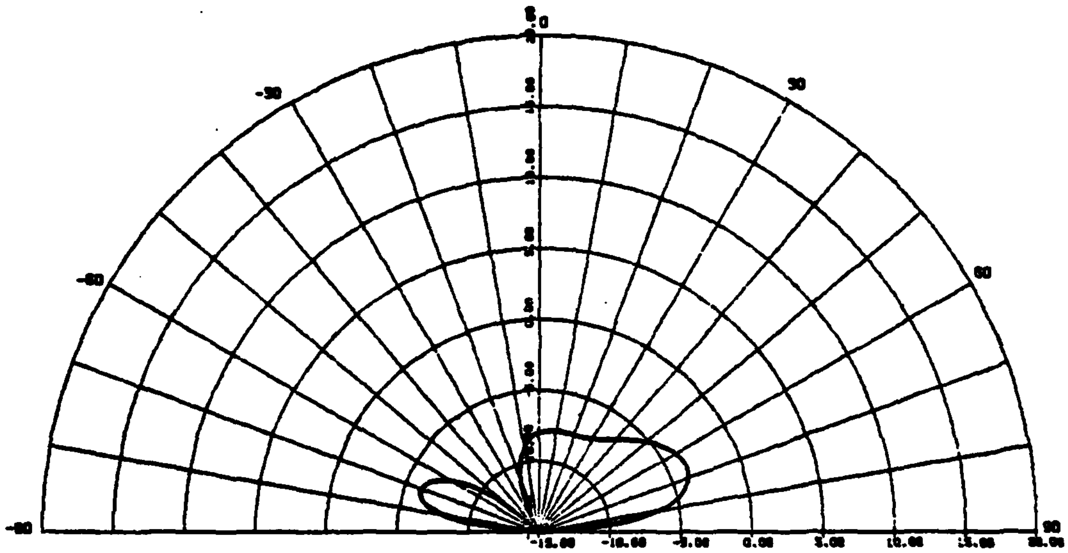
MAC-109 / PHI / THETA= 70

SNOW / JEEP / 30 MHZ



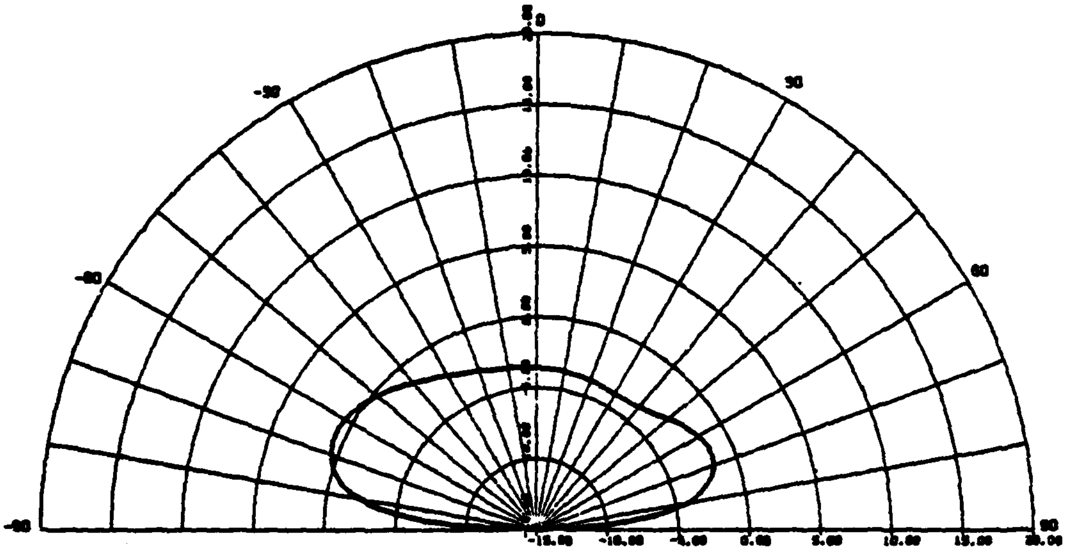
MAC-109 / THETA / PHI = 90

SNOW / JEEP / 30 MHZ



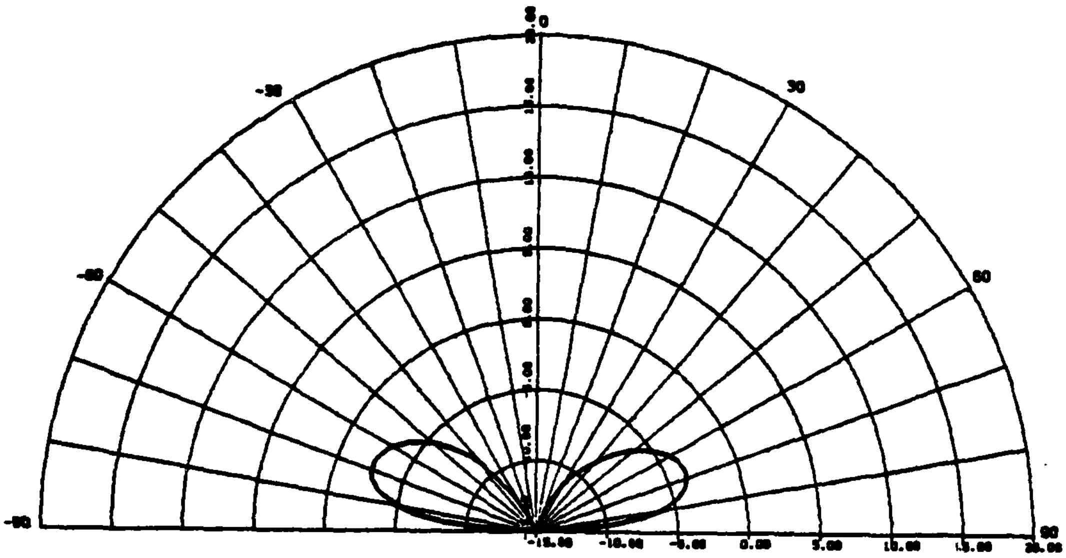
MAC-109 / THETA / PHI = 180

SNOW / JEEP / 30 MHZ



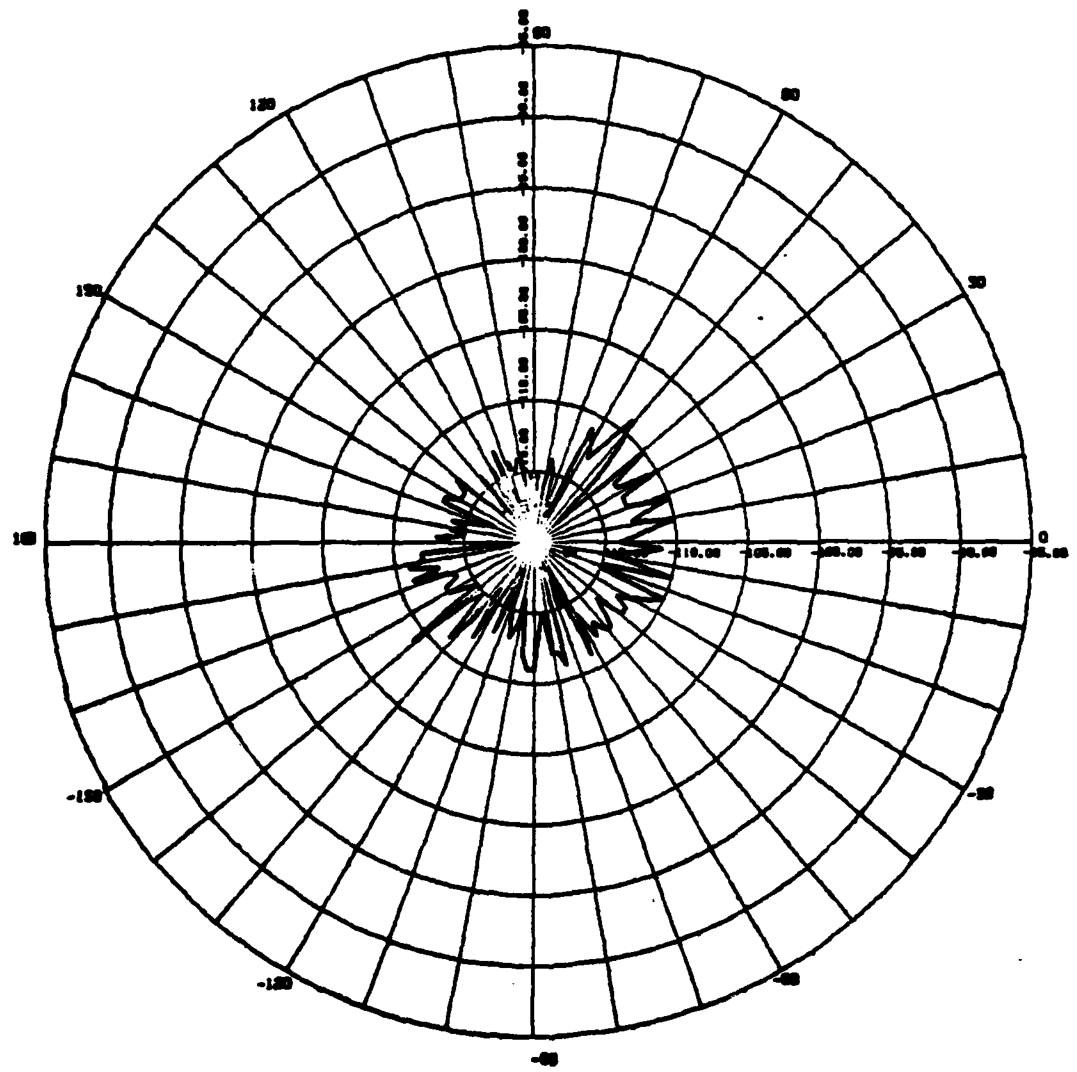
MAC-109 / THETA / PHI = 120

SNOW / JEEP / 30 MHZ



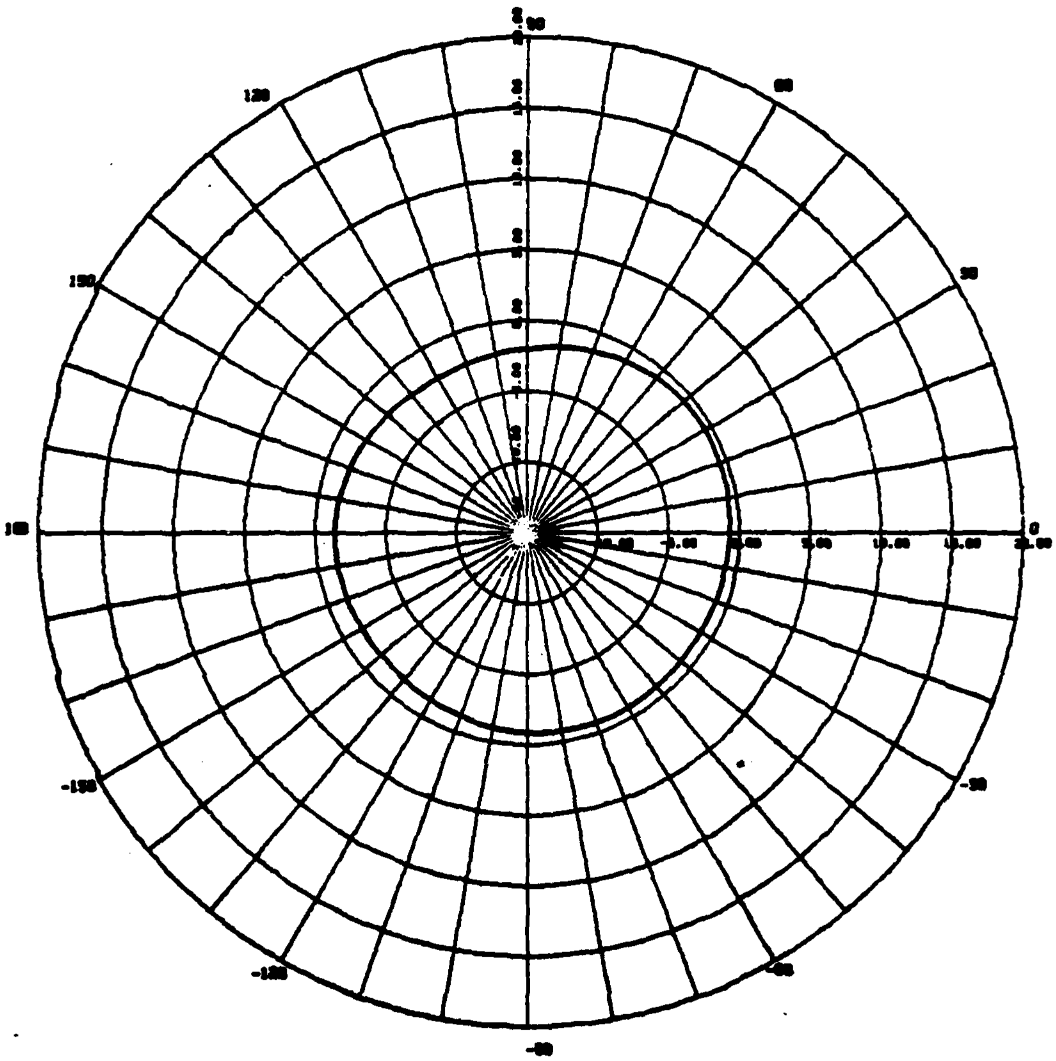
MAC-109 / PHI / THETA=90

SNOW / JEEP / 41 MHZ



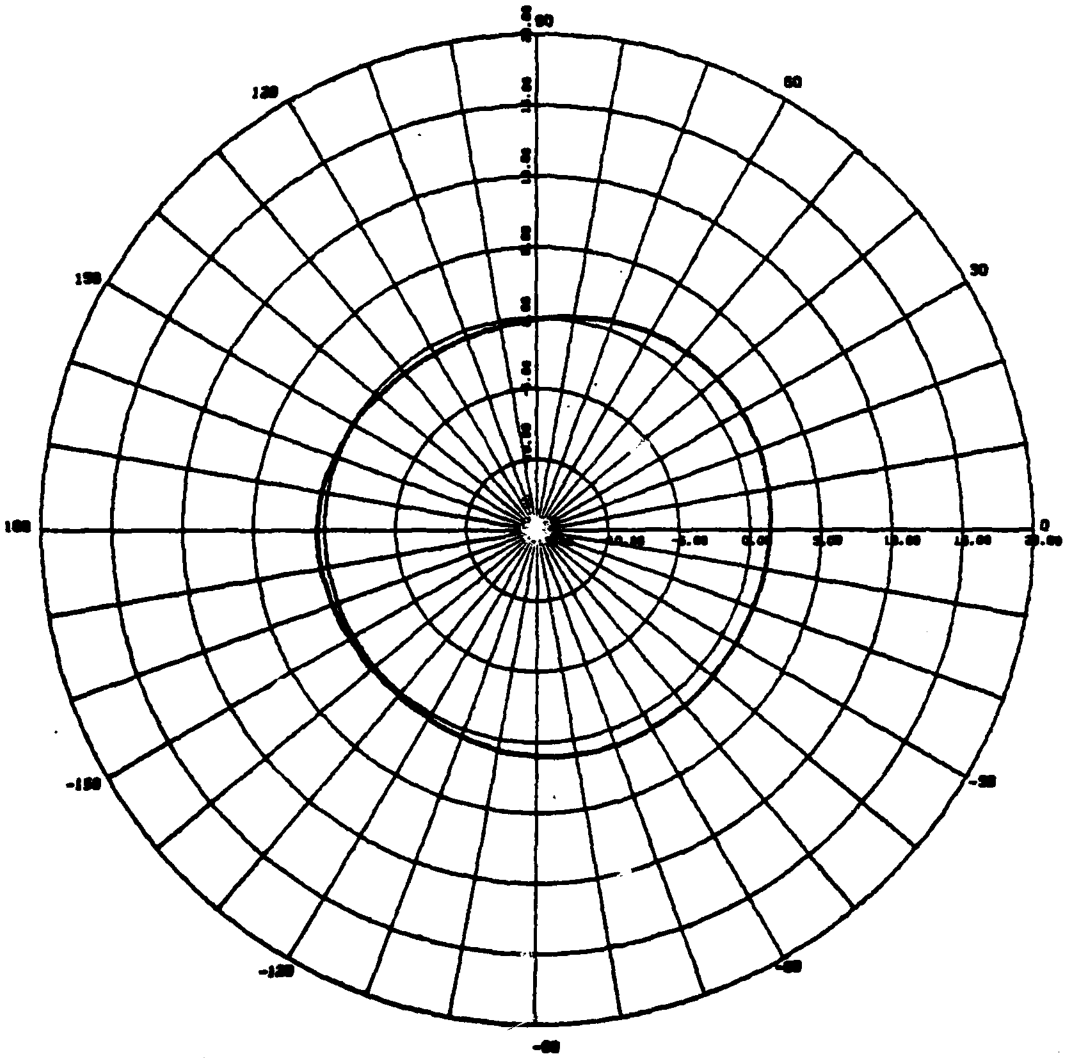
MRC-109 / PHI / THETA= 80

SNOW / JEEP / 41 MHZ



MAC-109 / PHI / THETA= 70

SNOW / JEEP / 41 MHZ



MRC-109 / THETA / PHI = 90

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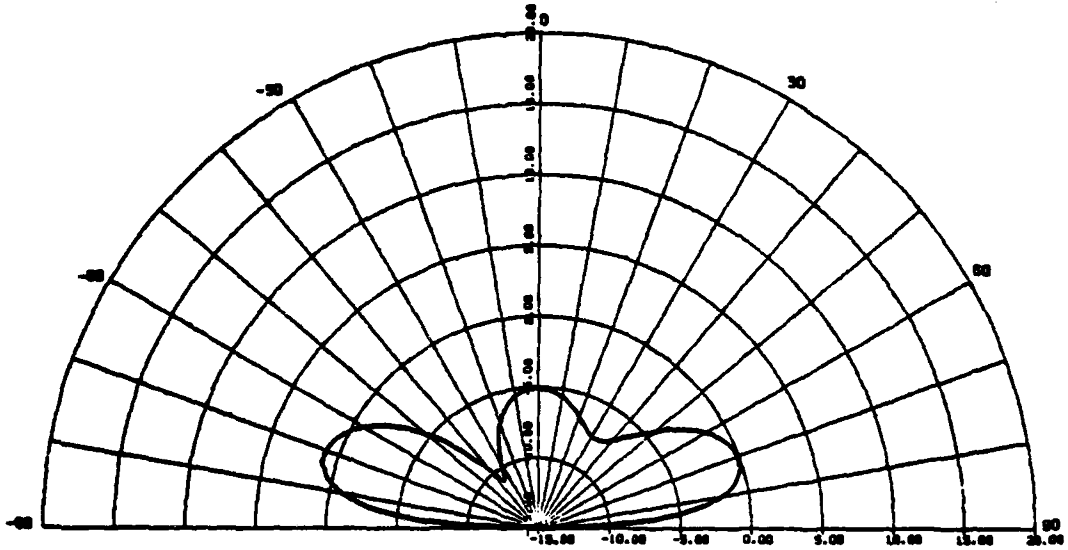
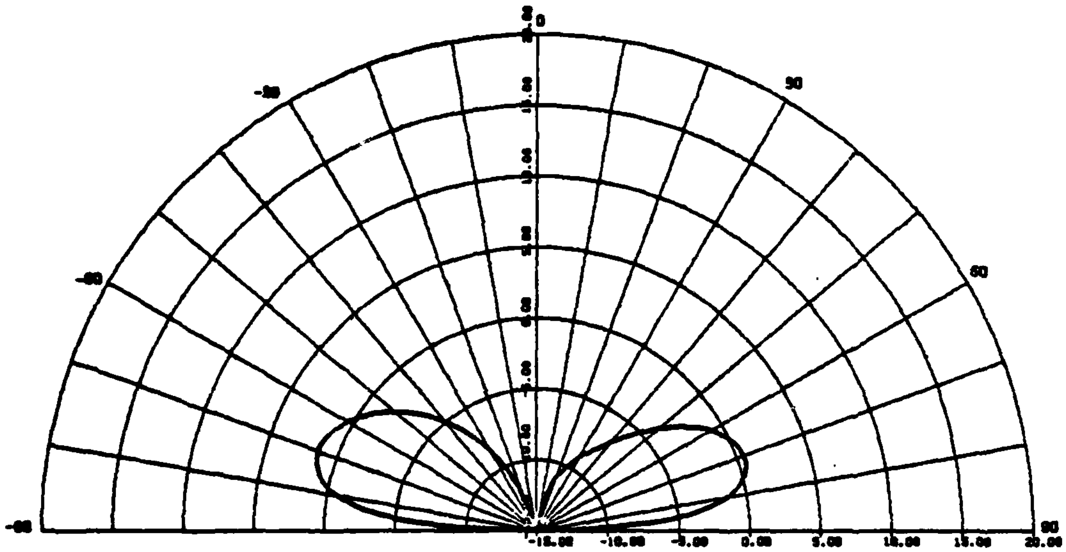


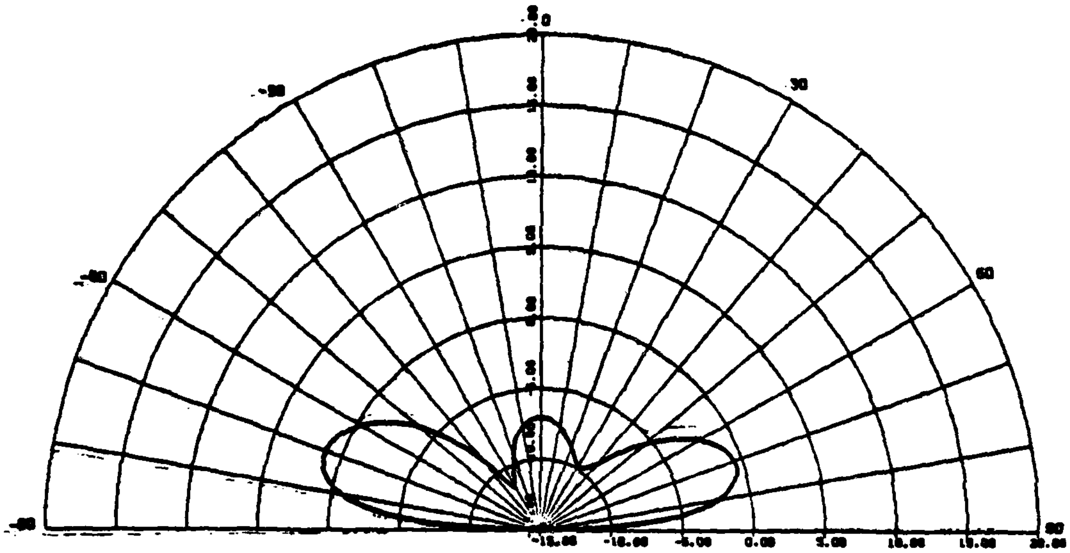
MAC-109 / THETA / PHI = 180

SNOW / JEEP / 41 MHZ



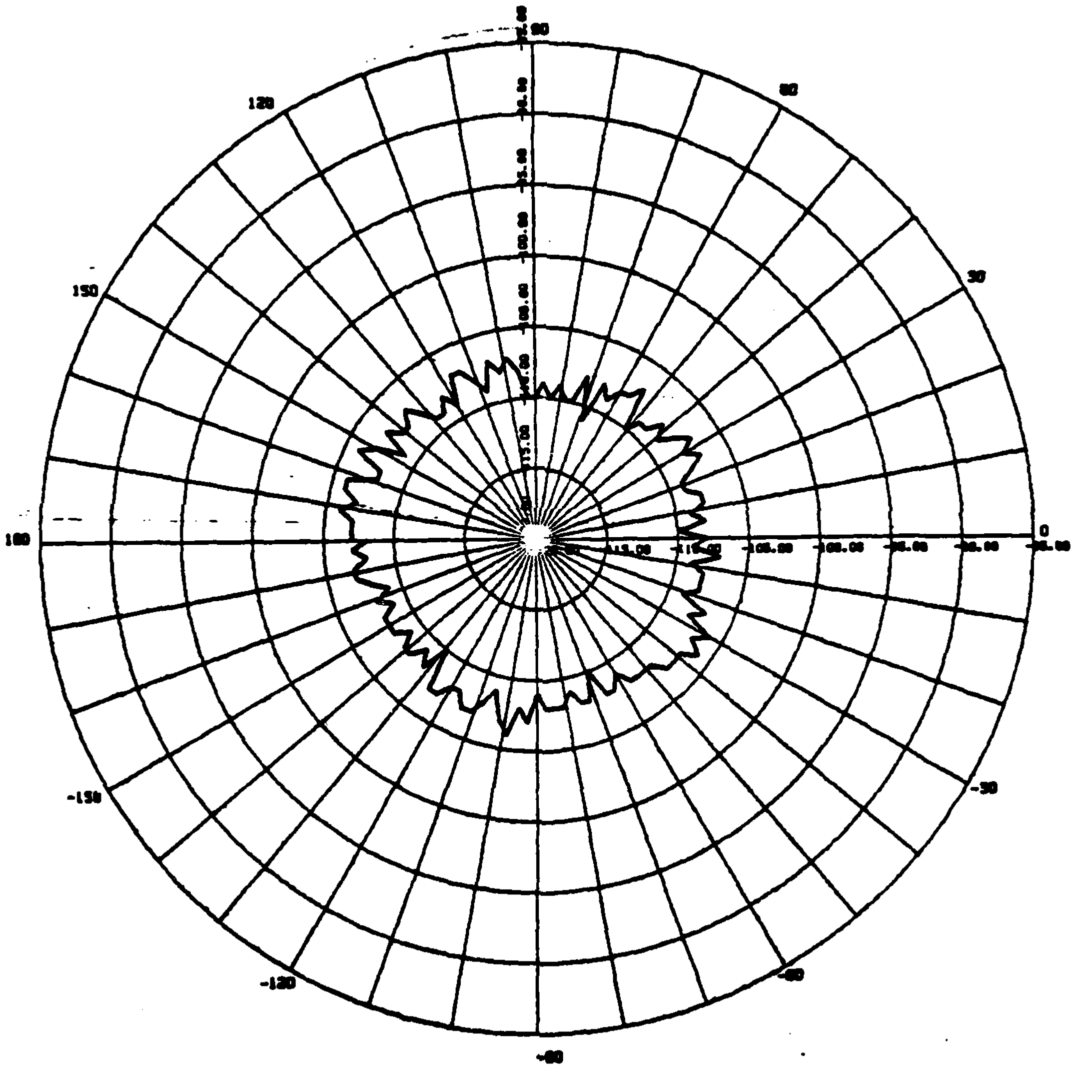
MAC-109 / THETA / PHI = I20

SNOW / JEEP / 41 MHZ



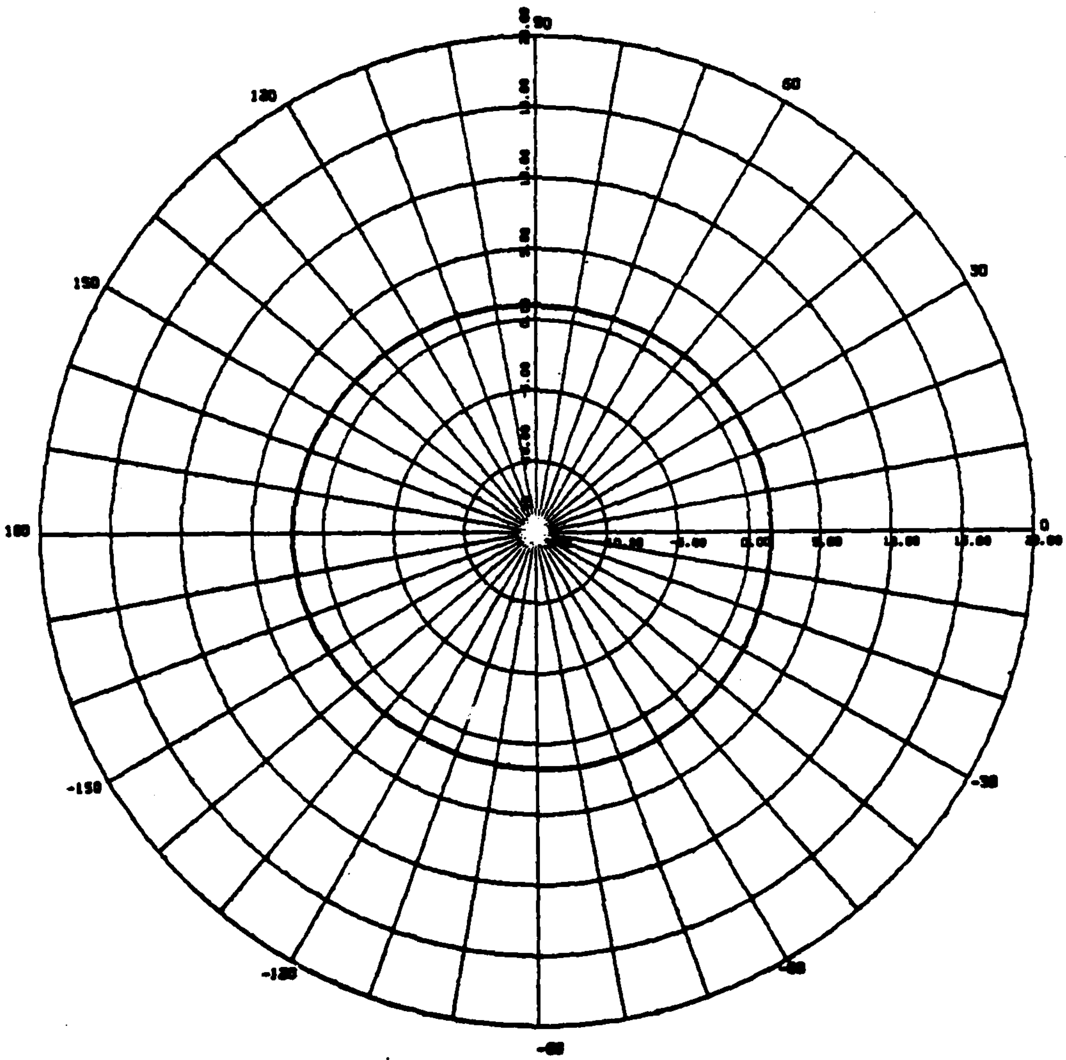
MAC-109 / PHI / THETA=90

SNOW / JEEP / 50 MHZ



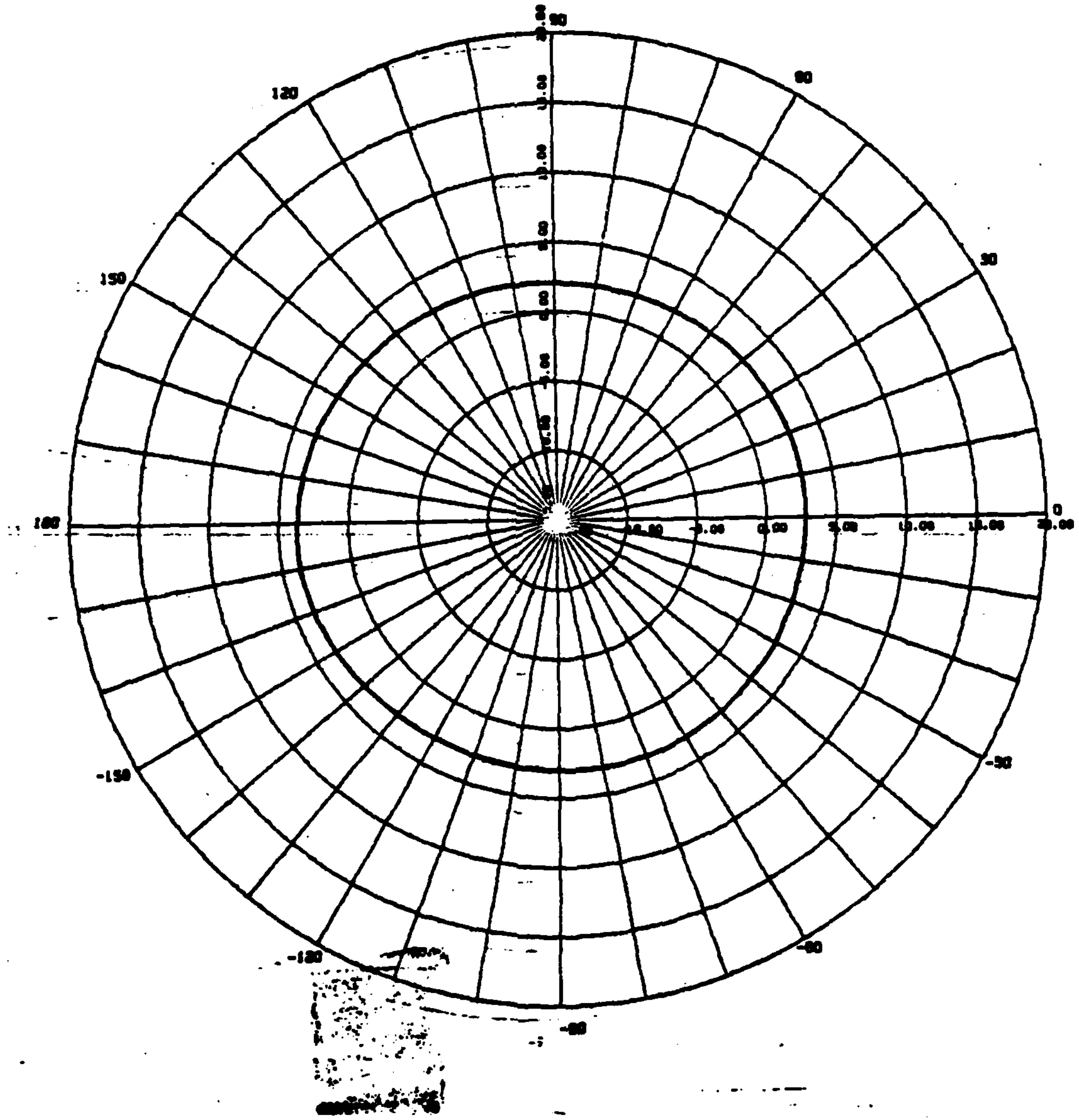
MRC-109 / PHI / THETA= 80

SNOW / JEEP / 50 MHZ



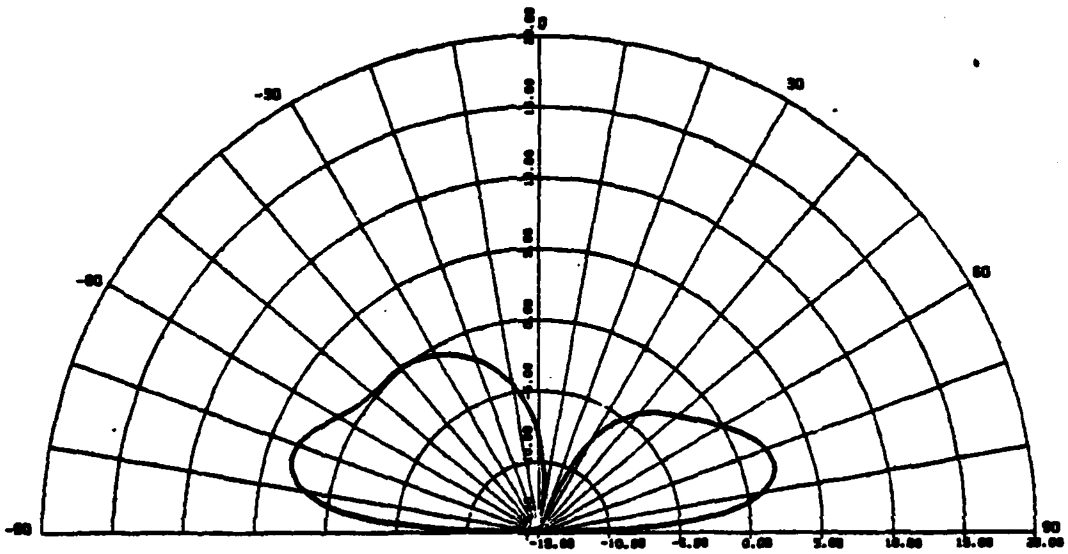
MAC-109 / PHI / THETA= 70

SNOW / JEEP / 50 MHZ



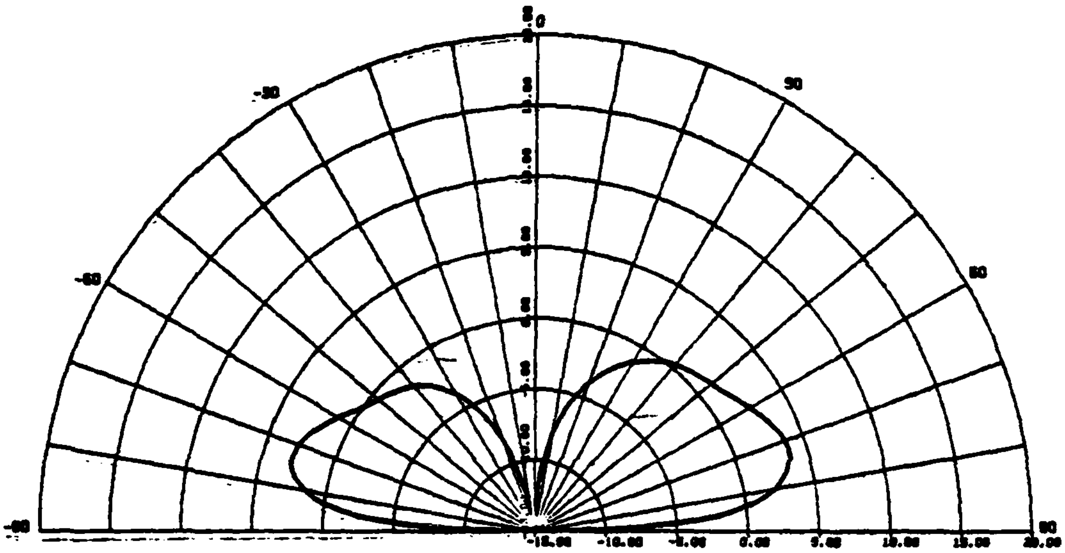
MAC-109 / THETA / PHI = 90

SNOW / JEEP / 50 MHZ



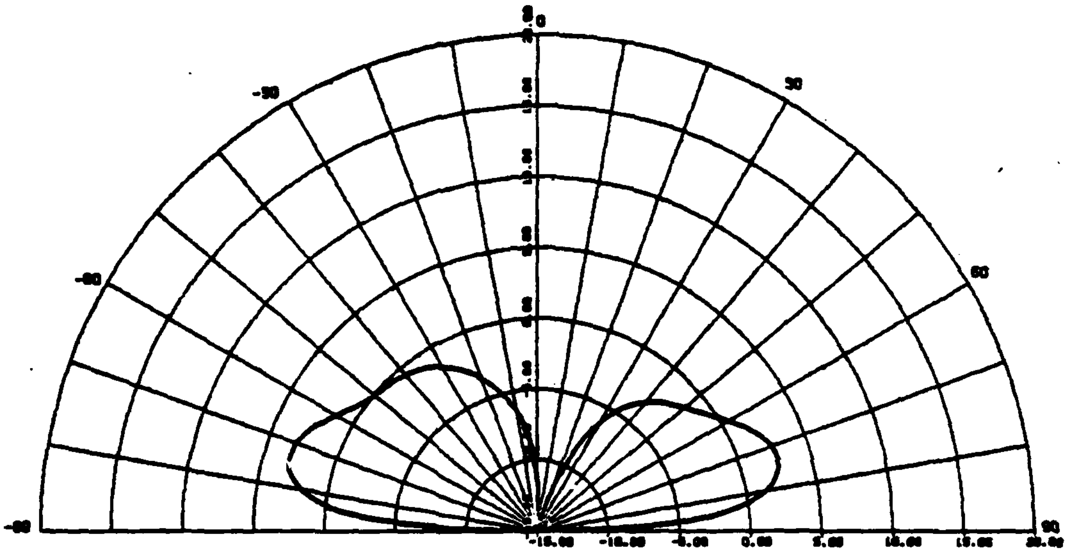
MAC-109 / THETA / PHI = 180

SNOW / JEEP / 50 MHZ



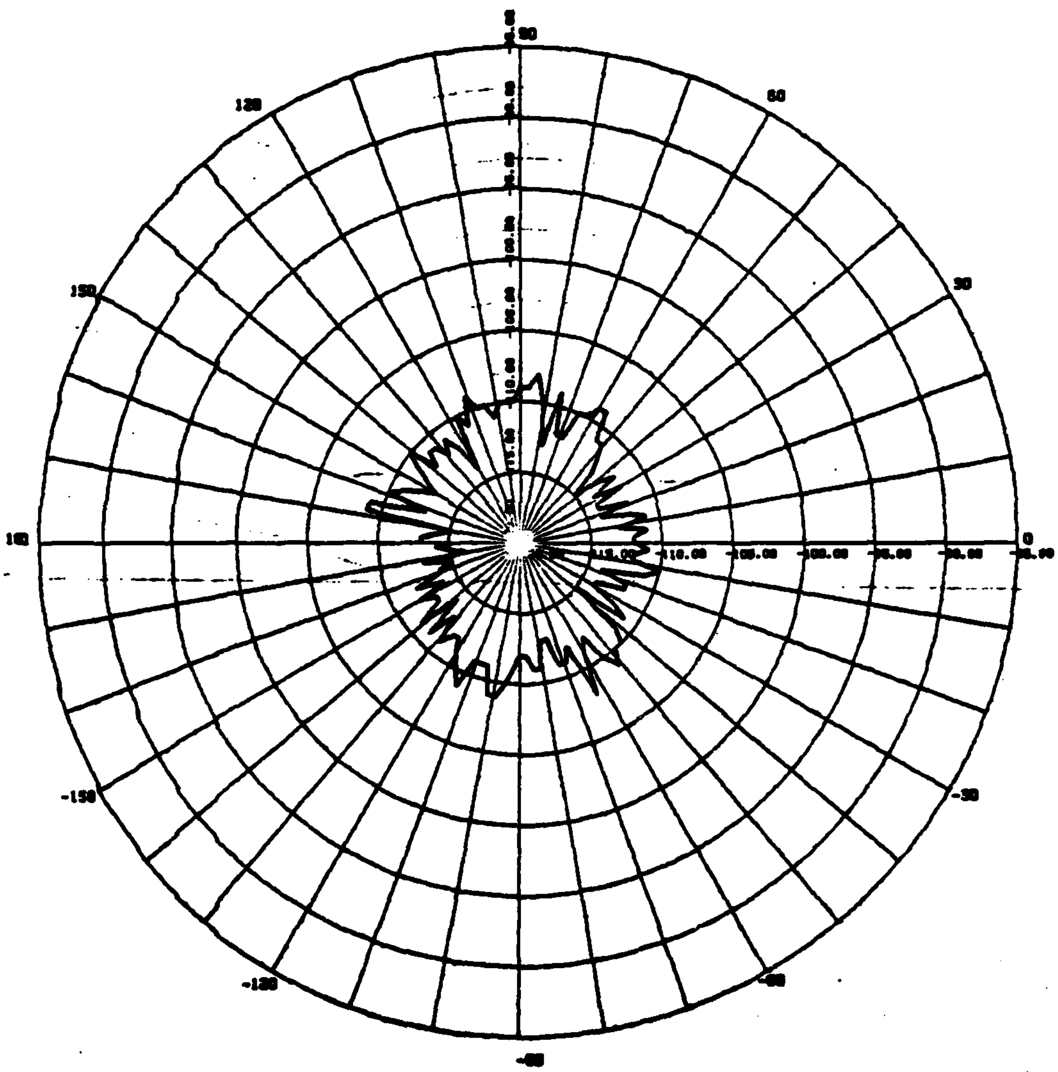
MAC-109 / THETA / PHI = 120

SNOW / JEEP / 50 MHZ



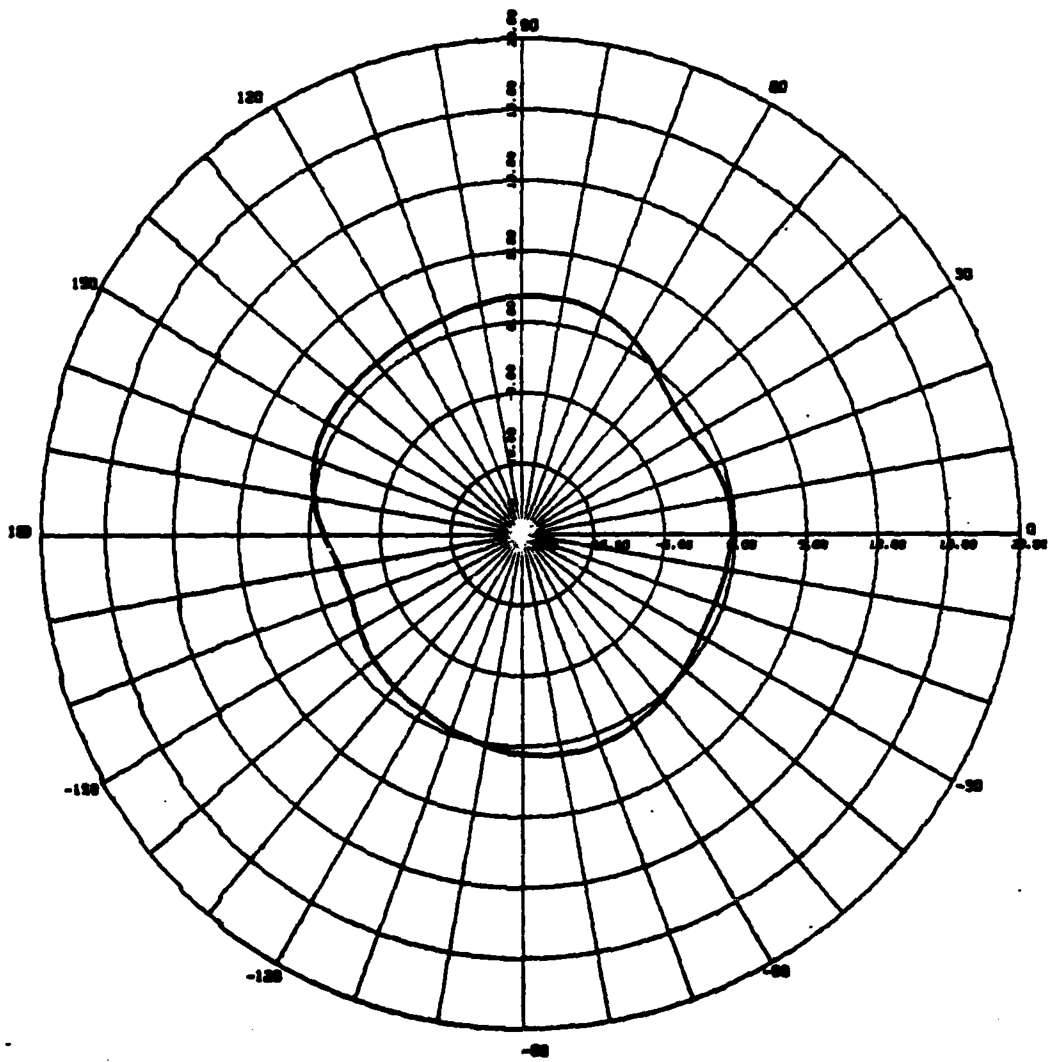
MAC-109 / PHI / THETA=90

SNOW / JEEP / 75 MHZ



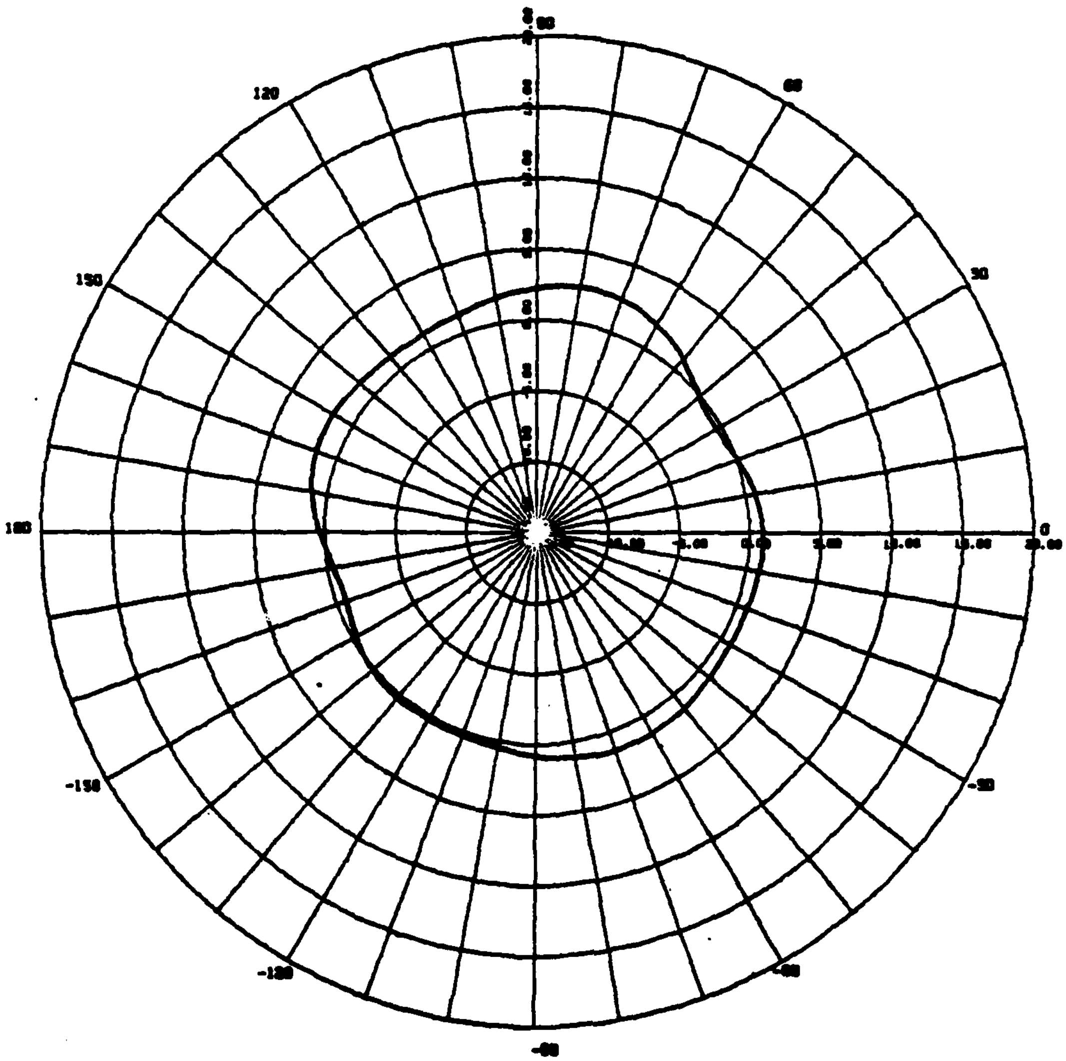
MAC-109 / PHI / THETA= 80

SNOW / JEEP / 75 MHZ



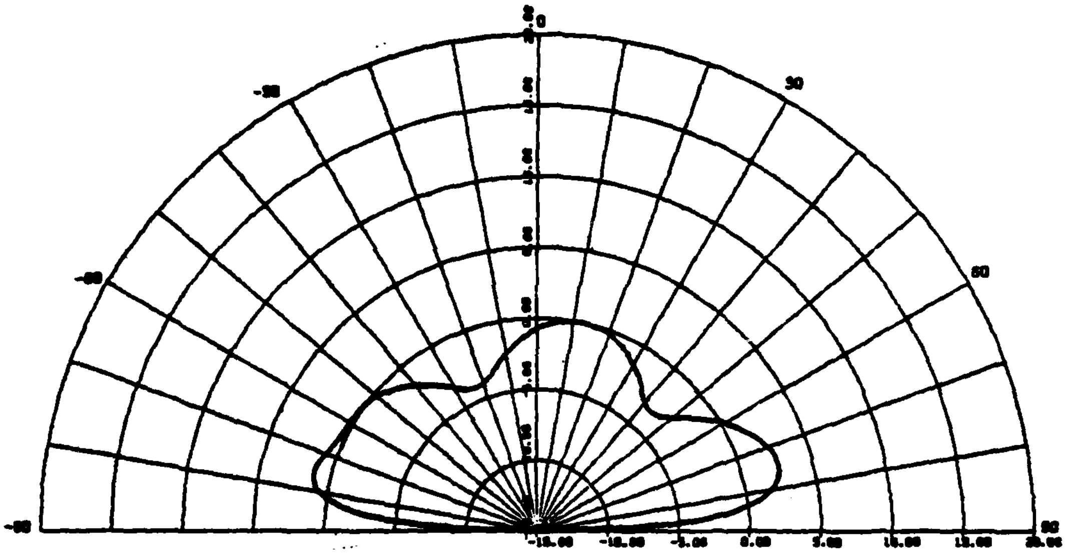
MAC-109 / PHI / THETA= 70

SNOW / JEEP / 75 MHZ



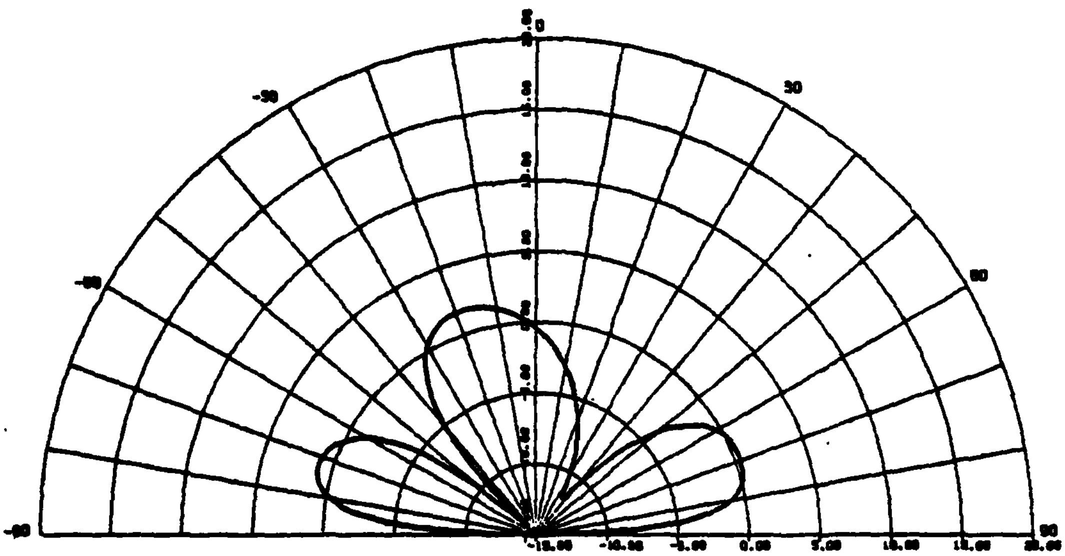
MAC-109 / THETA / PHI = 90

SNOW / JEEP / 75 MHZ



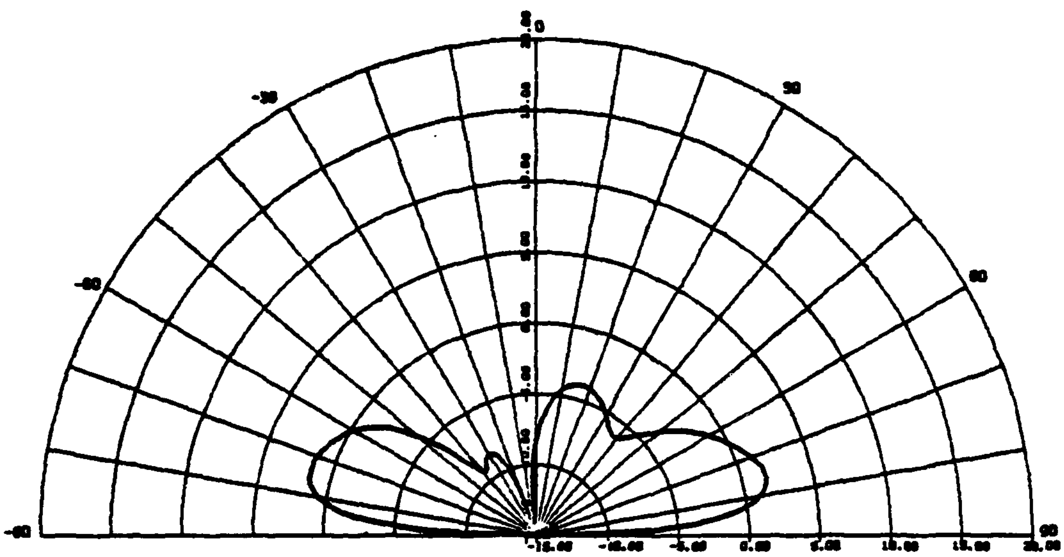
MAC-109 / THETA / PHI = 180

SNOW / JEEP / 75 MHZ



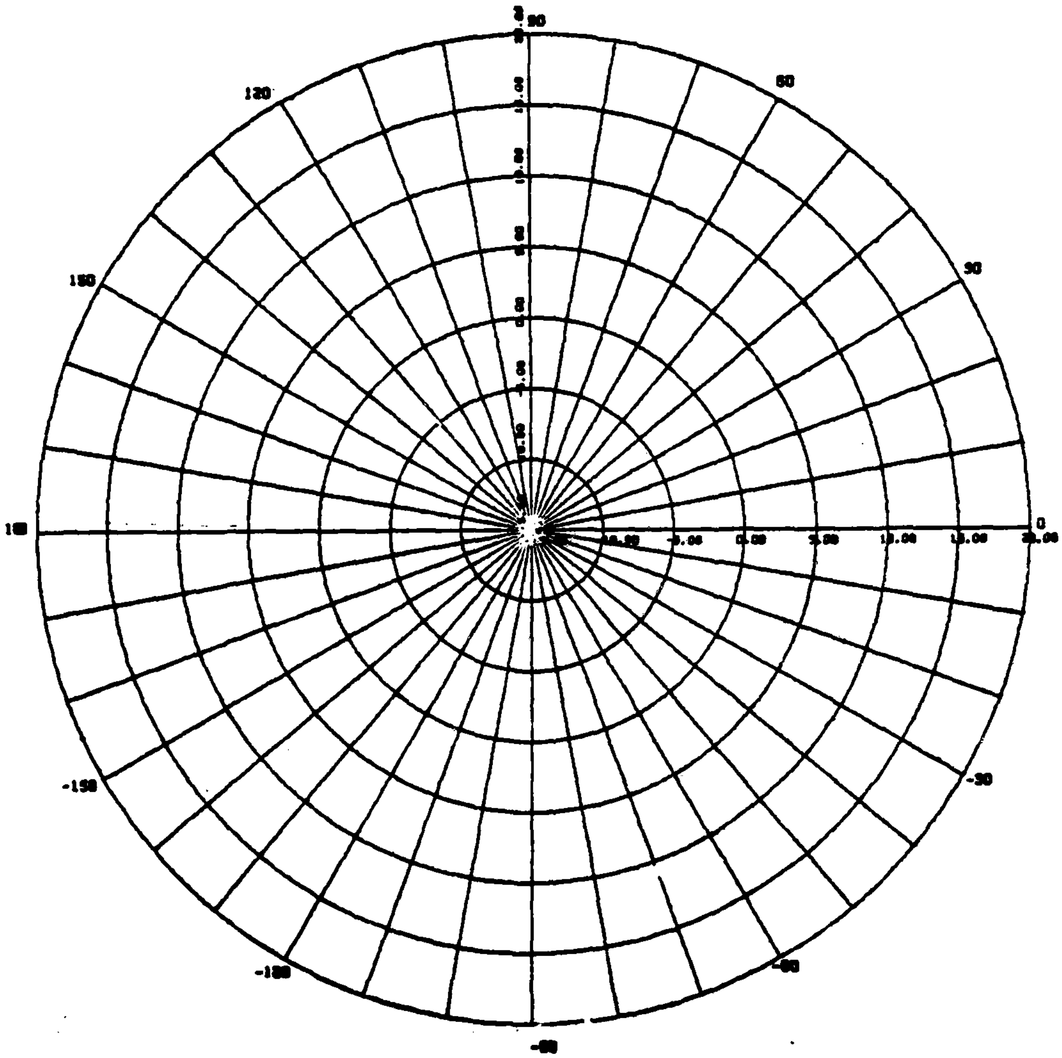
MAC-109 / THETA / PHI = 120

SNOW / JEEP / 75 MHZ



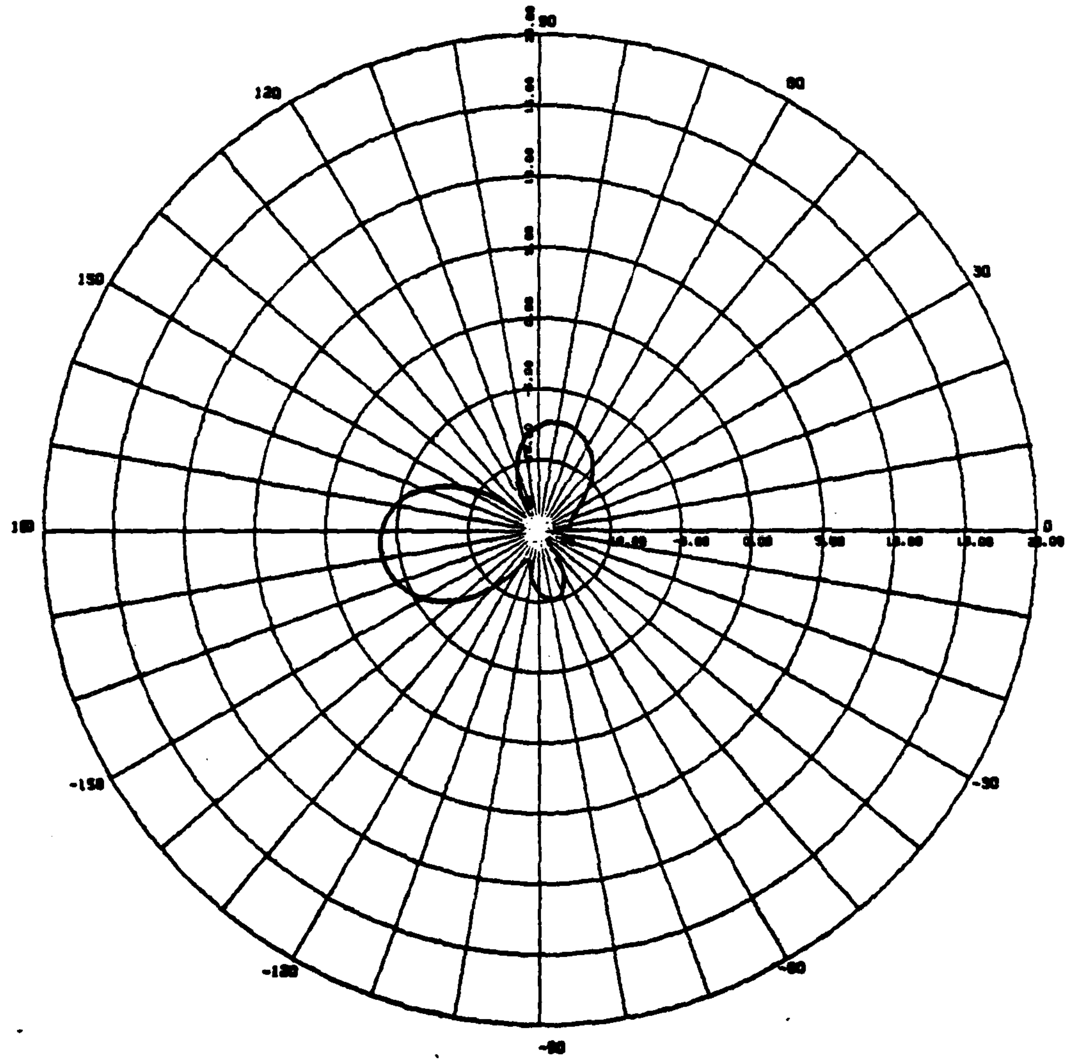
MAC-109 / PHI / THETA=90

SNOW / JEEP & TALA / 30 MHZ



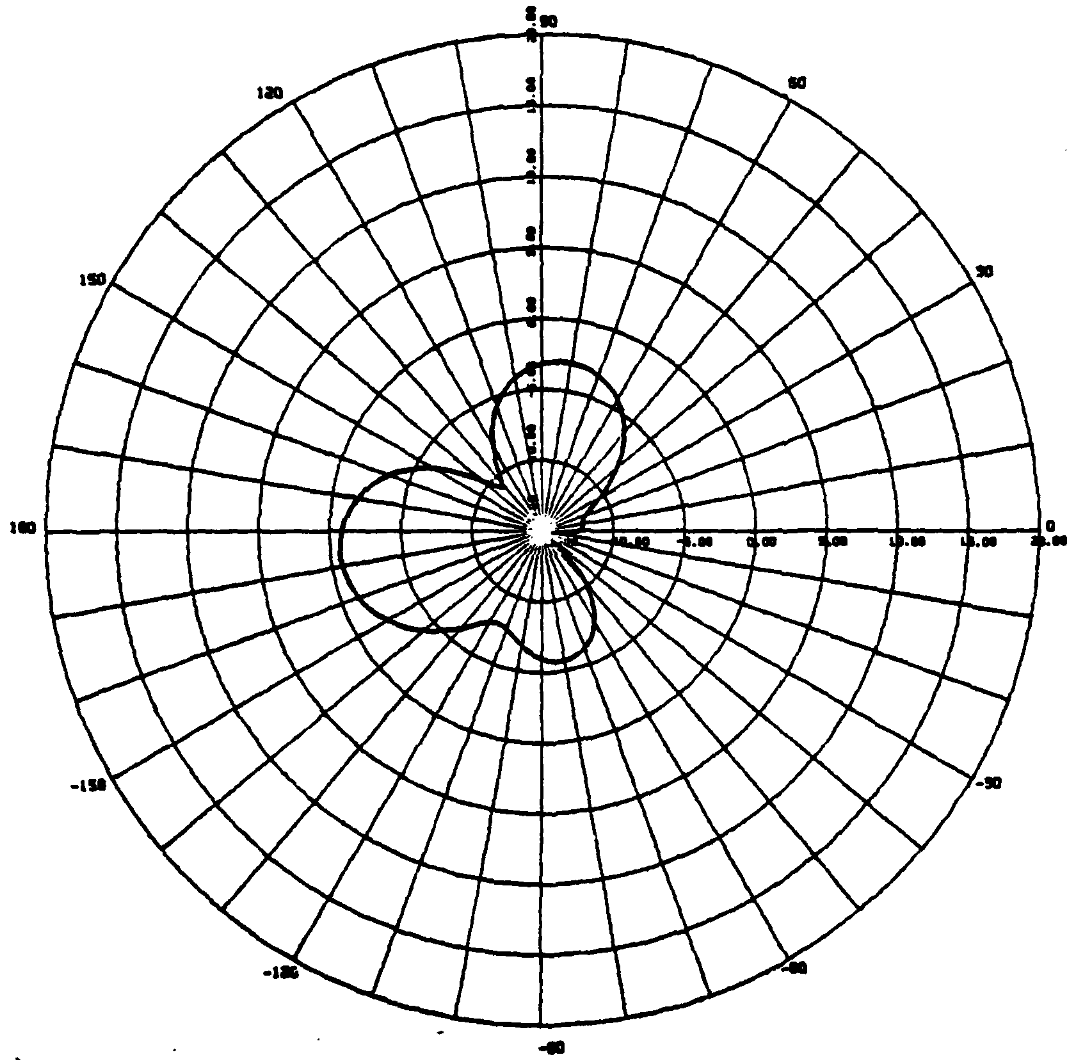
MRC-109 / PHI / THETA=80

SNOW / JEEP & TALA / 30 MHZ



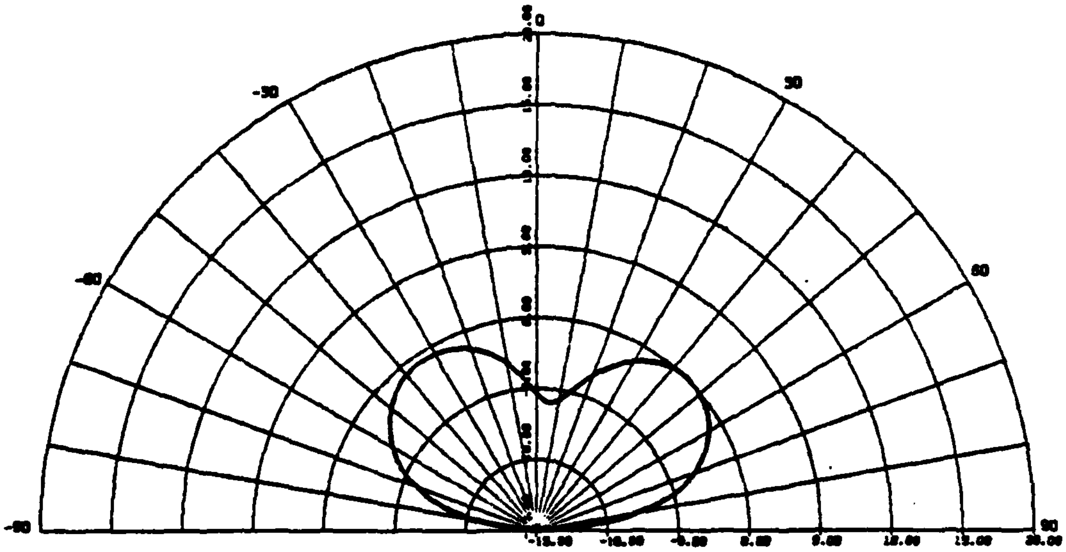
MAC-109 / PHI / THETA=70

SNOW / JEEP & TALA / 30 MHZ



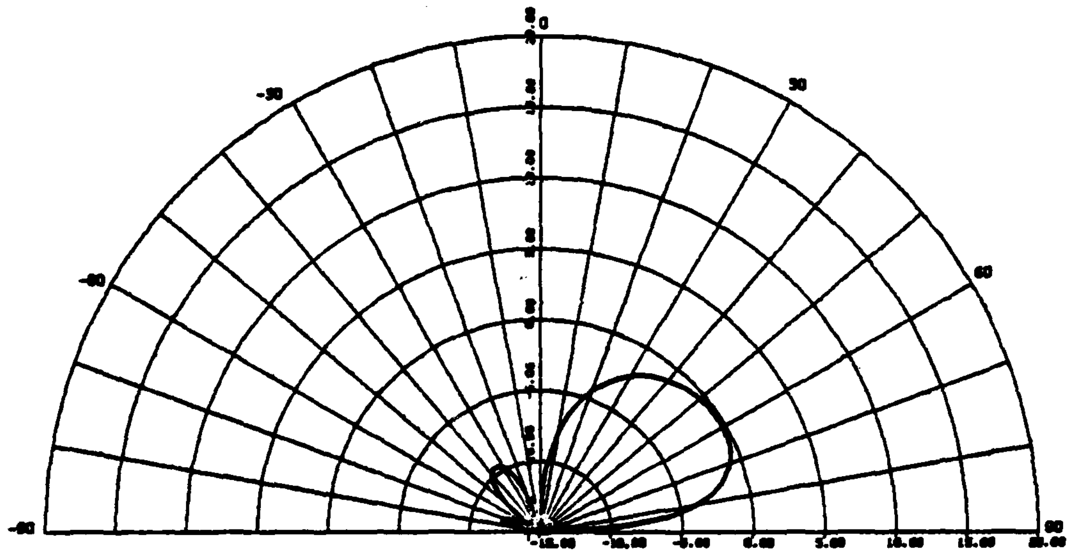
MAC-109 / THETA / PHI=90

SNOW / JEEP & TALA / 30 MHZ



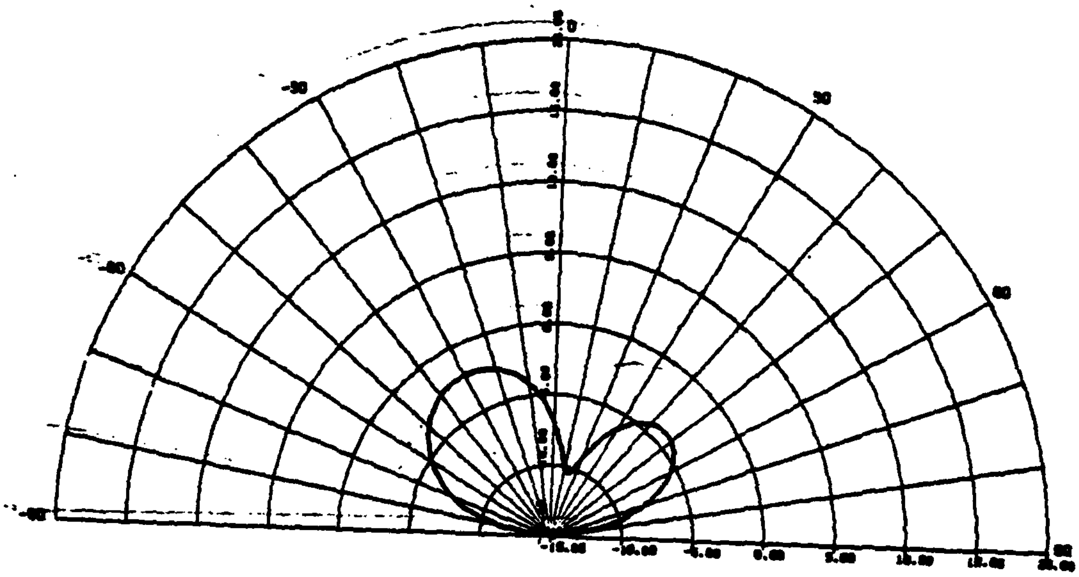
MAC-109 / THETA / PHI=180

SNOW / JEEP & TALA / 30 MHZ



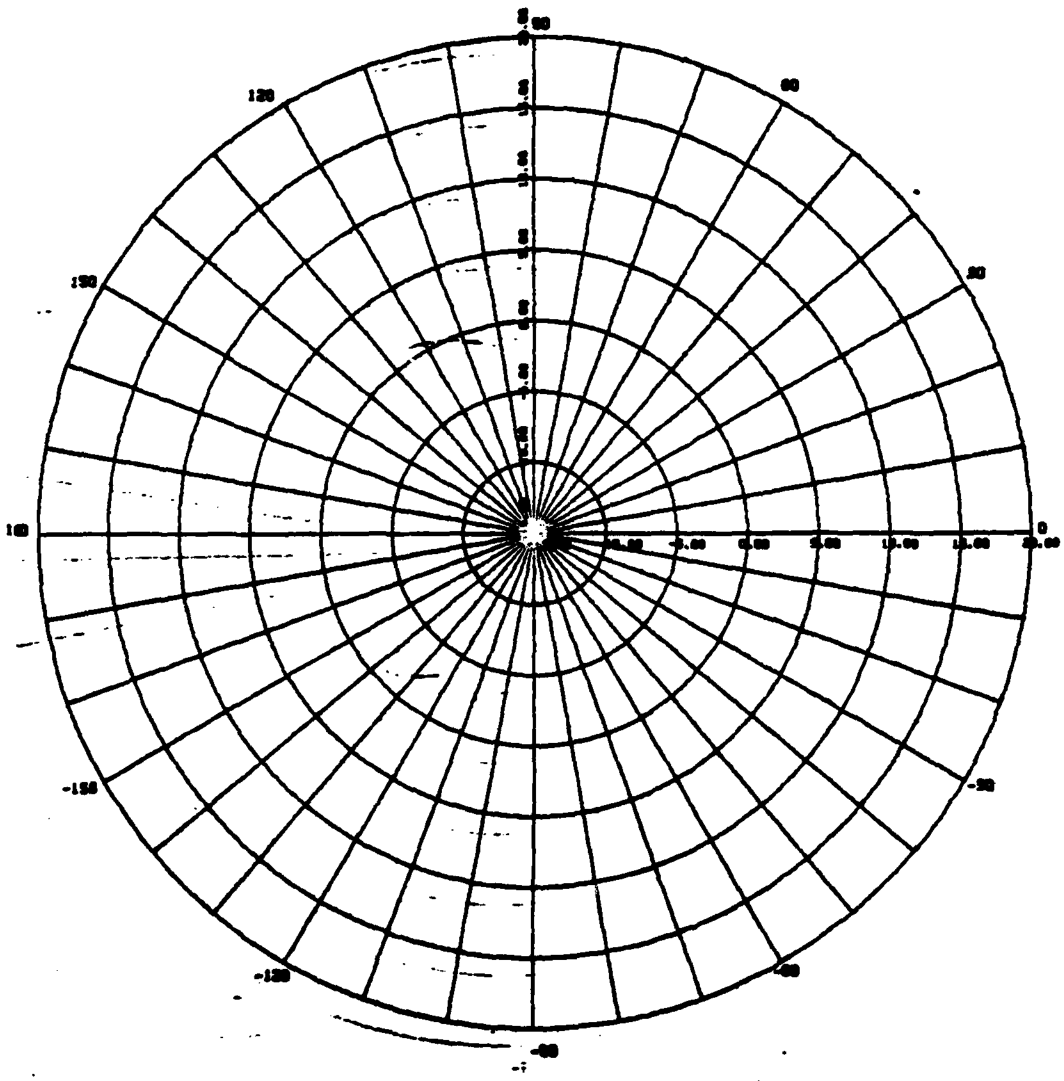
MAC-109 / THETA / PHI=120

SNOW / JEEP & TALA / 30 MHZ



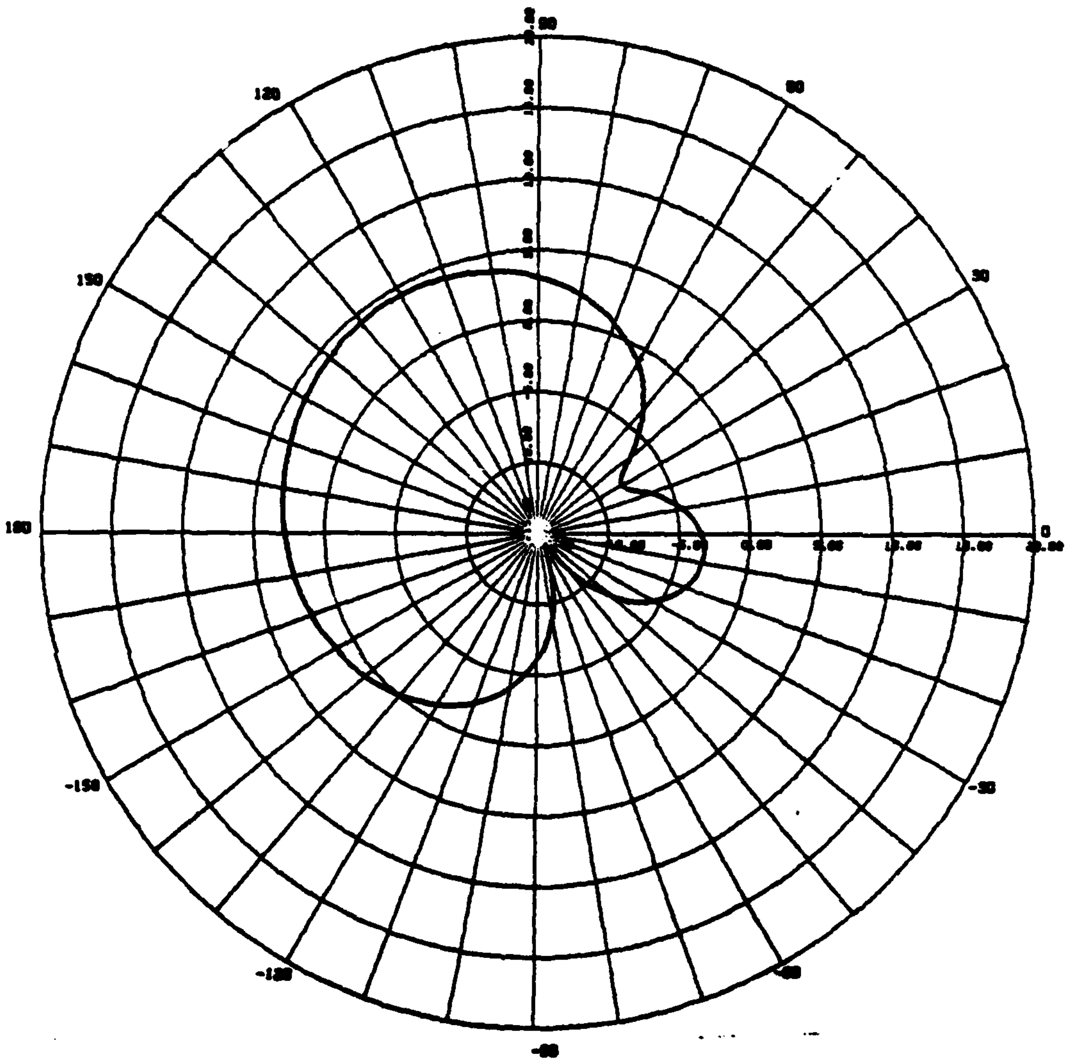
MAC-109 / PHI / THETA=90

SNOW / JEEP & TALA / 41 MHZ



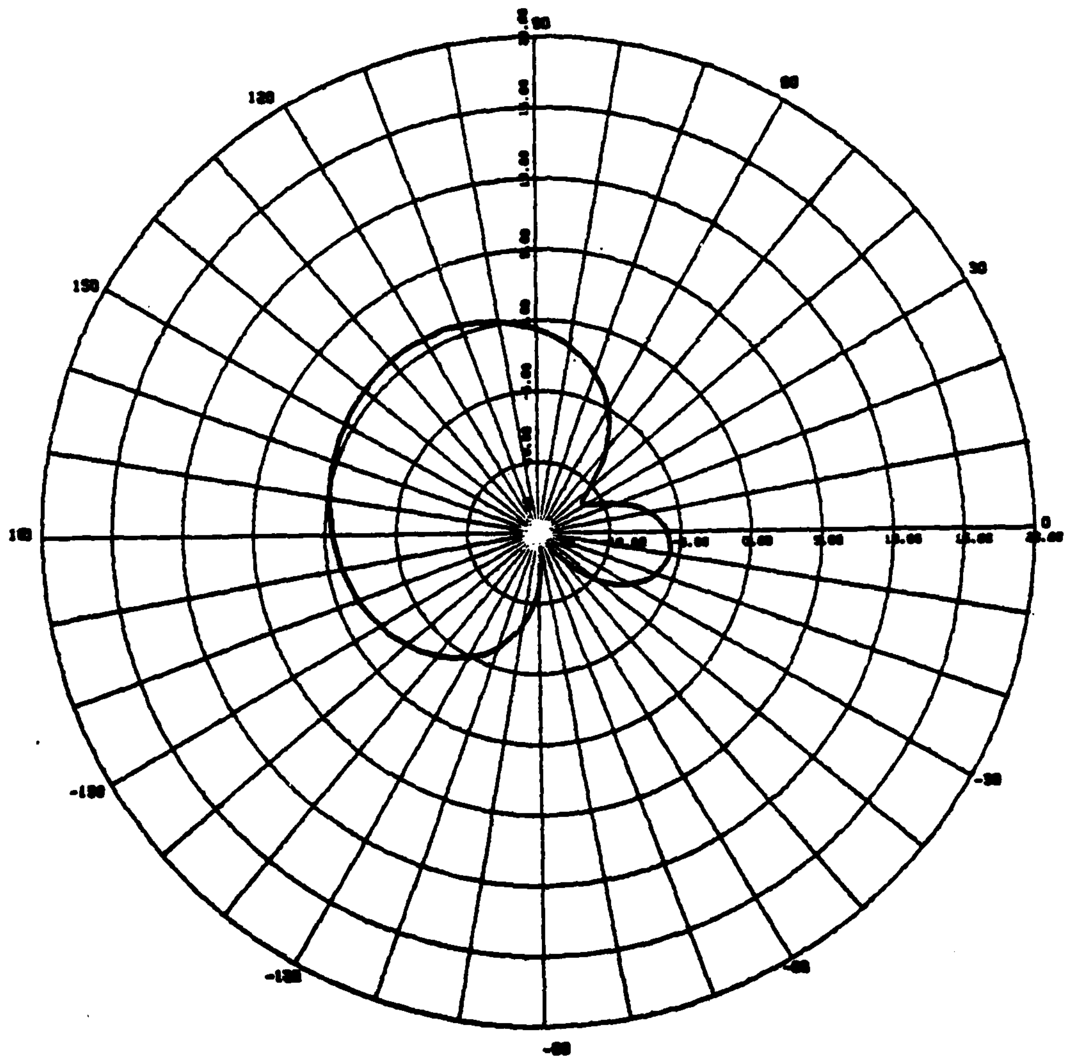
MAC-109 / PHI / THETA=70

SNOW / JEEP & TALA / 41 MHZ



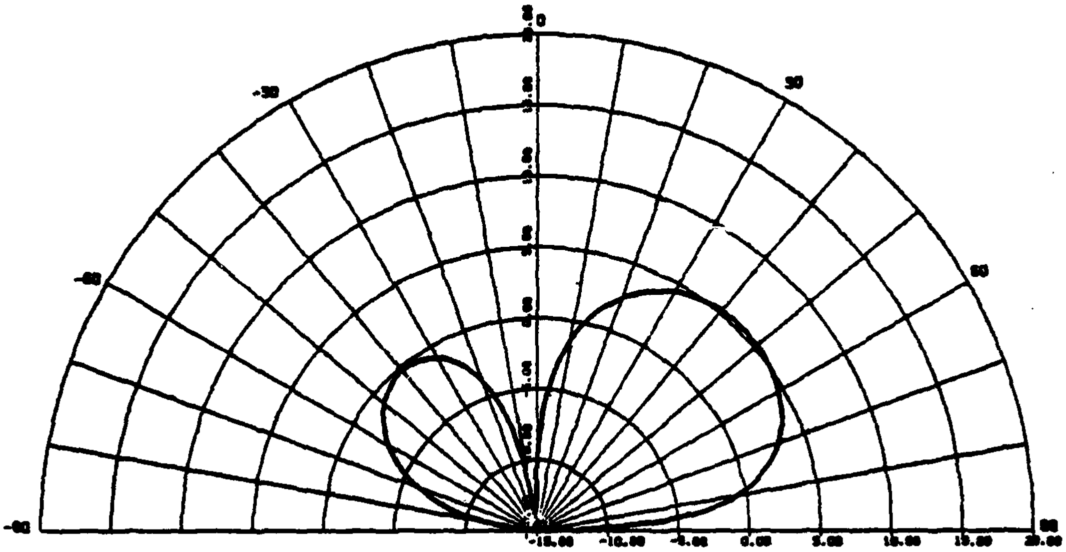
MAC-109 / PHI / THETA=80

SNOW / JEEP & RALA / 41 MHZ



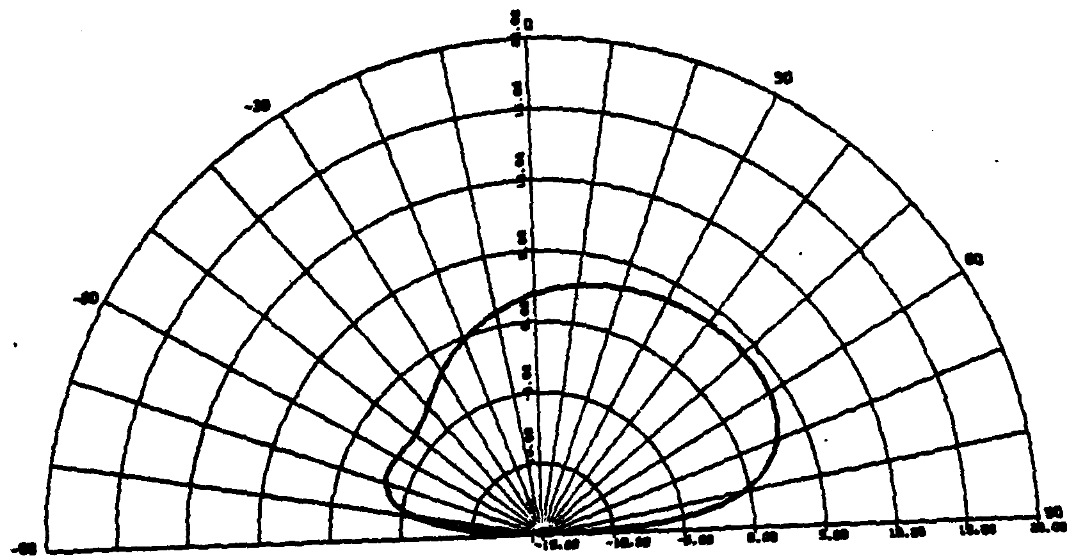
MAC-109 / THETA / PHI=90

SNOW / JEEP & TALA / 41 MHZ



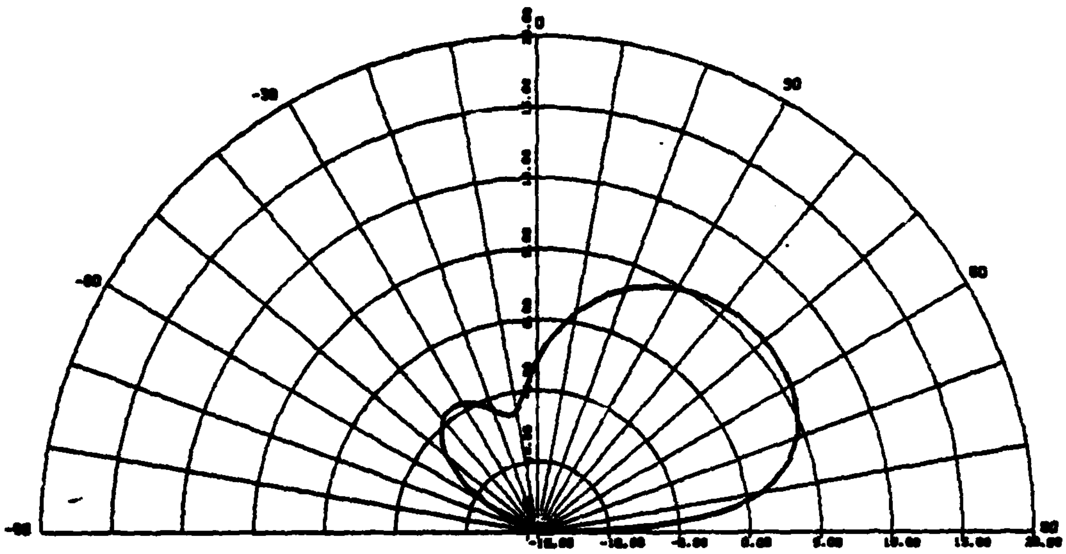
MAC-109 / THETA / PHI=180

SNOW / JEEP & TALA / 41 MHZ



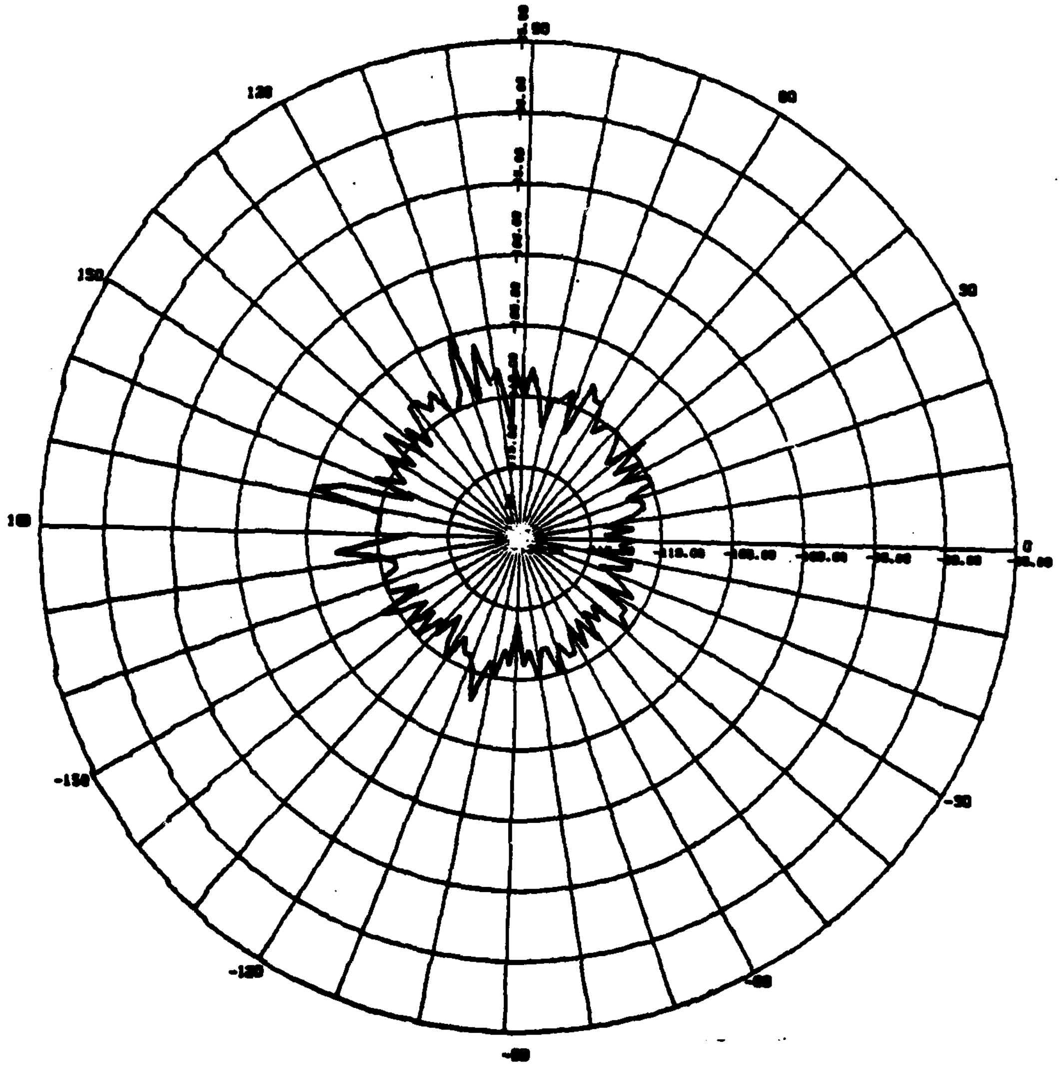
MAC-109 / THETA / PHI=120

SNOW / JEEP & TALA / 41 MHZ



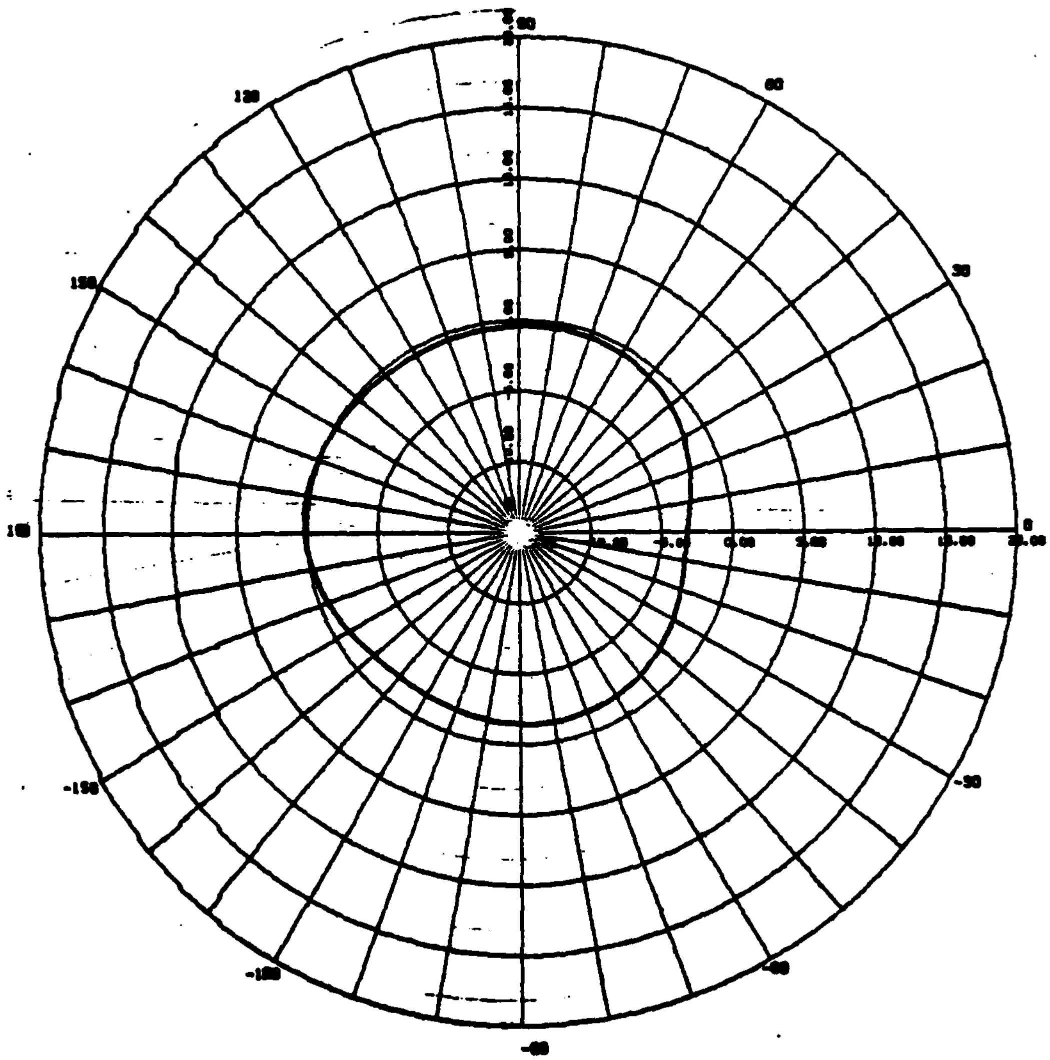
MAC-109 / PHI / THETA=90

SNOW / JEEP & TALA / 50 MHZ



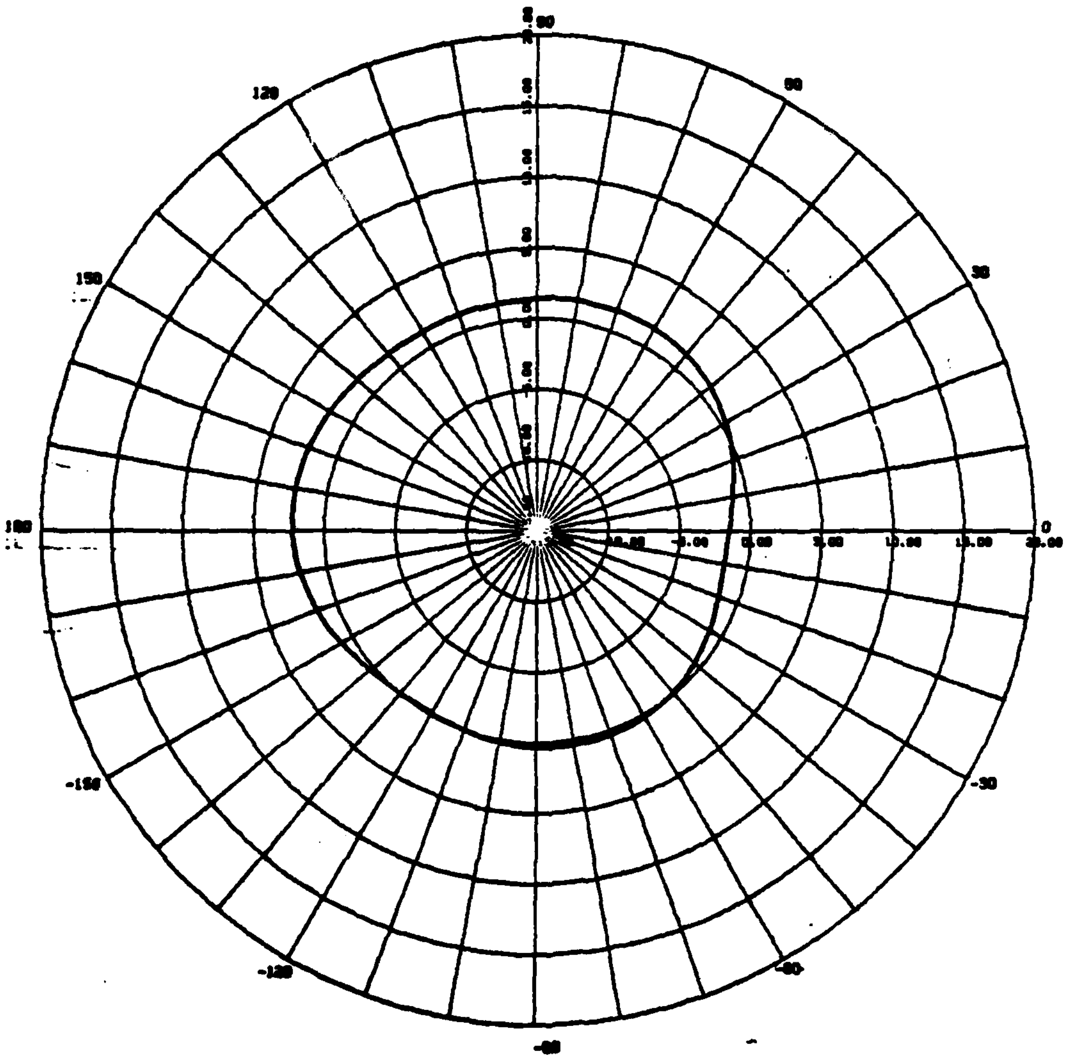
MAC-109 / PHI / THETA=80

SNOW / JEEP & TALA / 50 MHZ



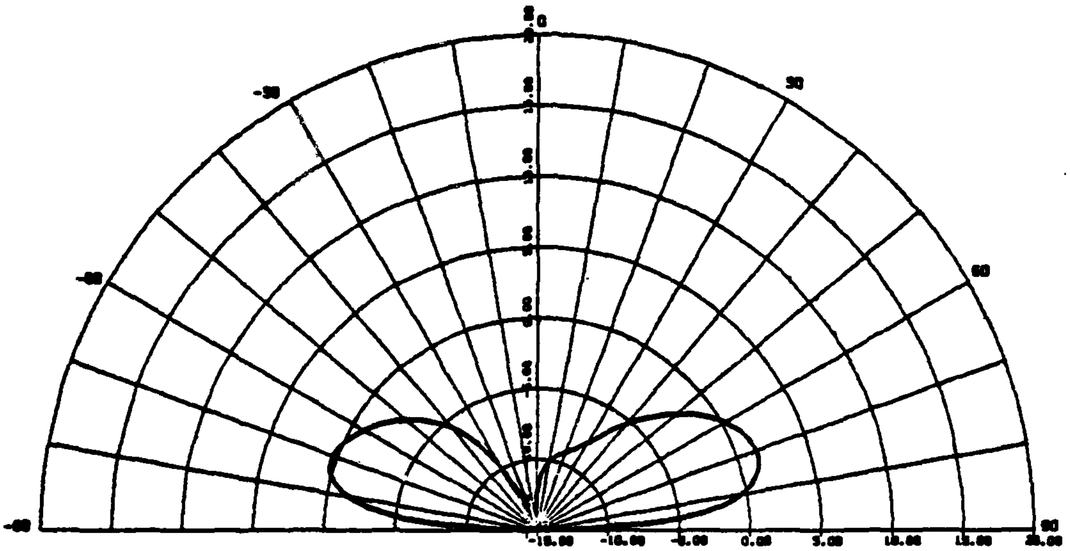
MAC-109 / PHI / THETA=70

SNOW / JEEP & TALA / 50 MHZ



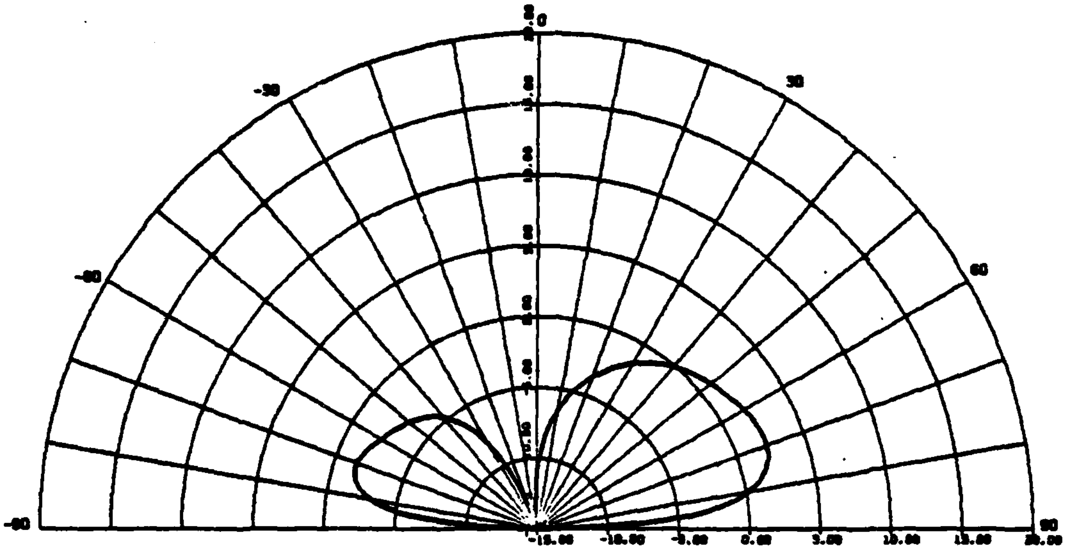
MAC-109 / THETA / PHI=90

SNOW / JEEP & TALA / 50 MHZ



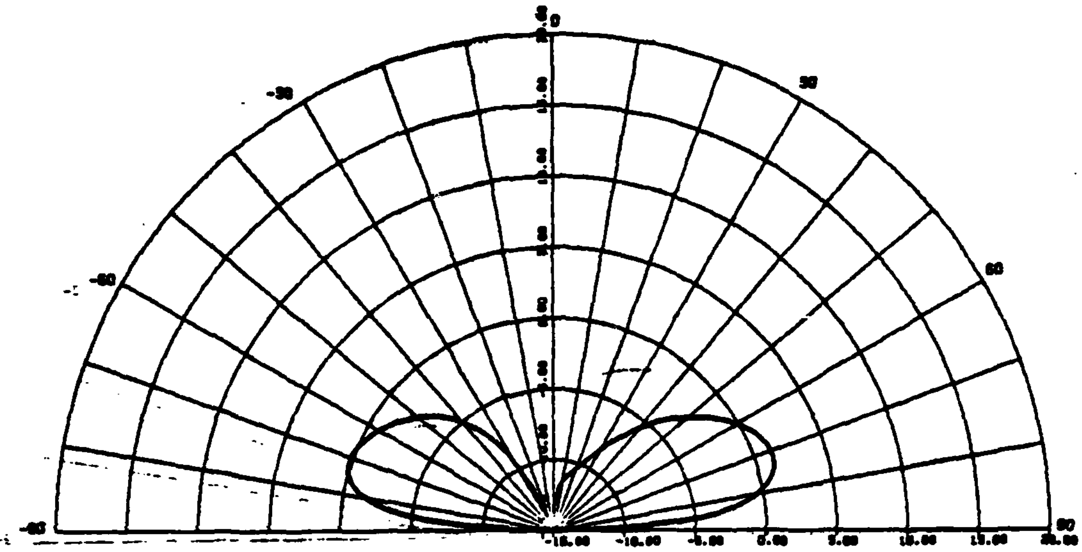
MAC-109 / THETA / PHI=180

SNOW / JEEP & TALA / 50 MHZ



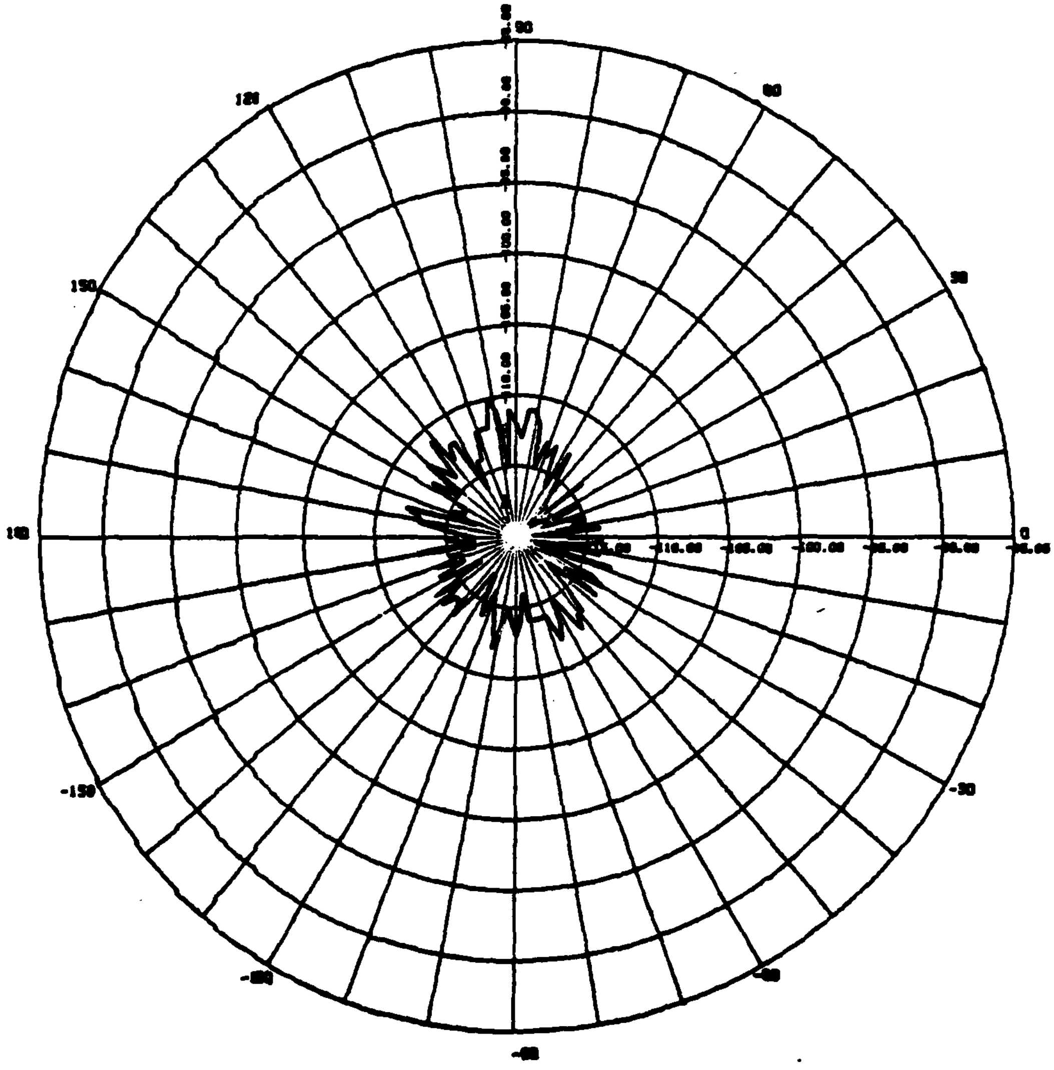
-MAC-109 / THETA / PHI=120

SNOW / JEEP & TALA / 50 MHZ



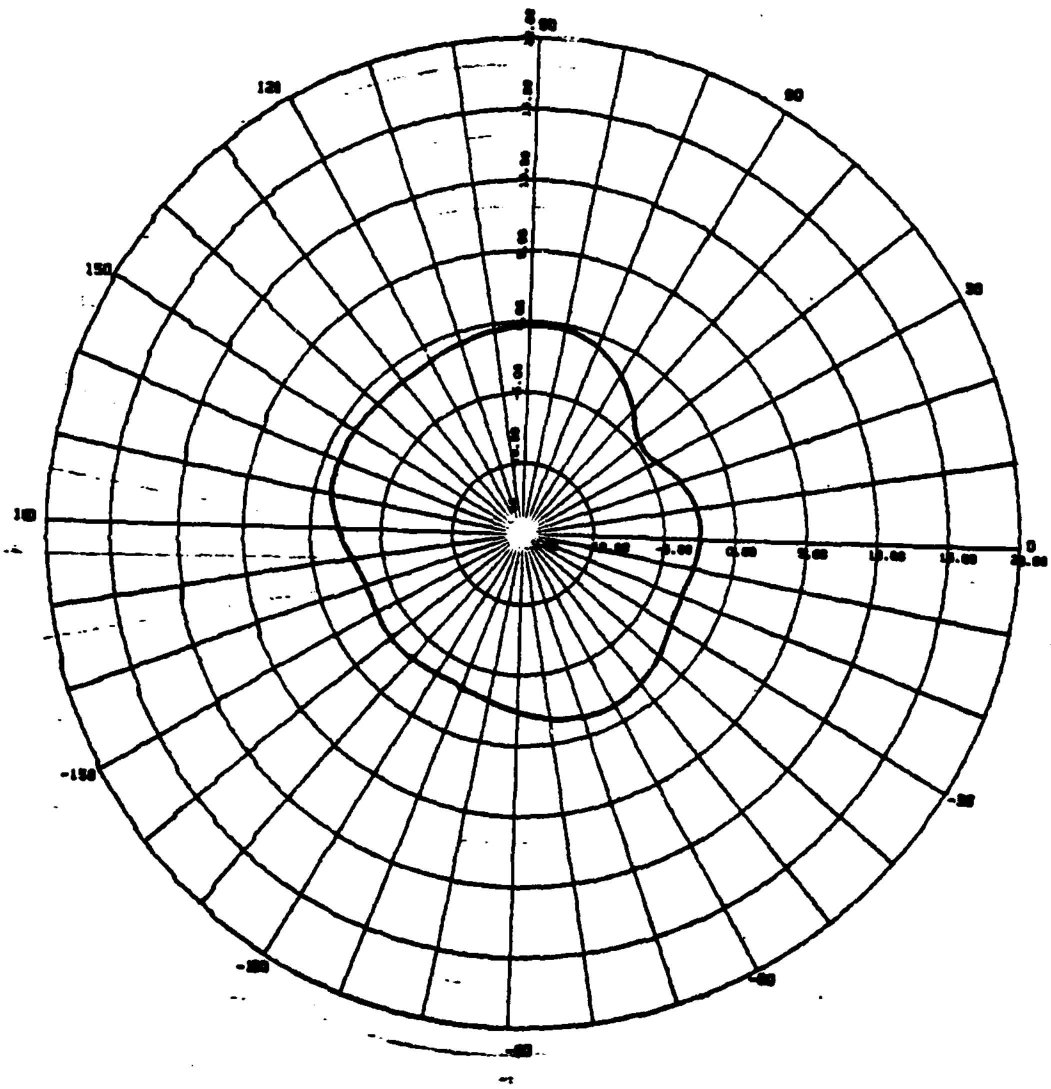
MAC-109 / PHI / THETA=90

SNOW / JEEP & TALA / 75 MHZ



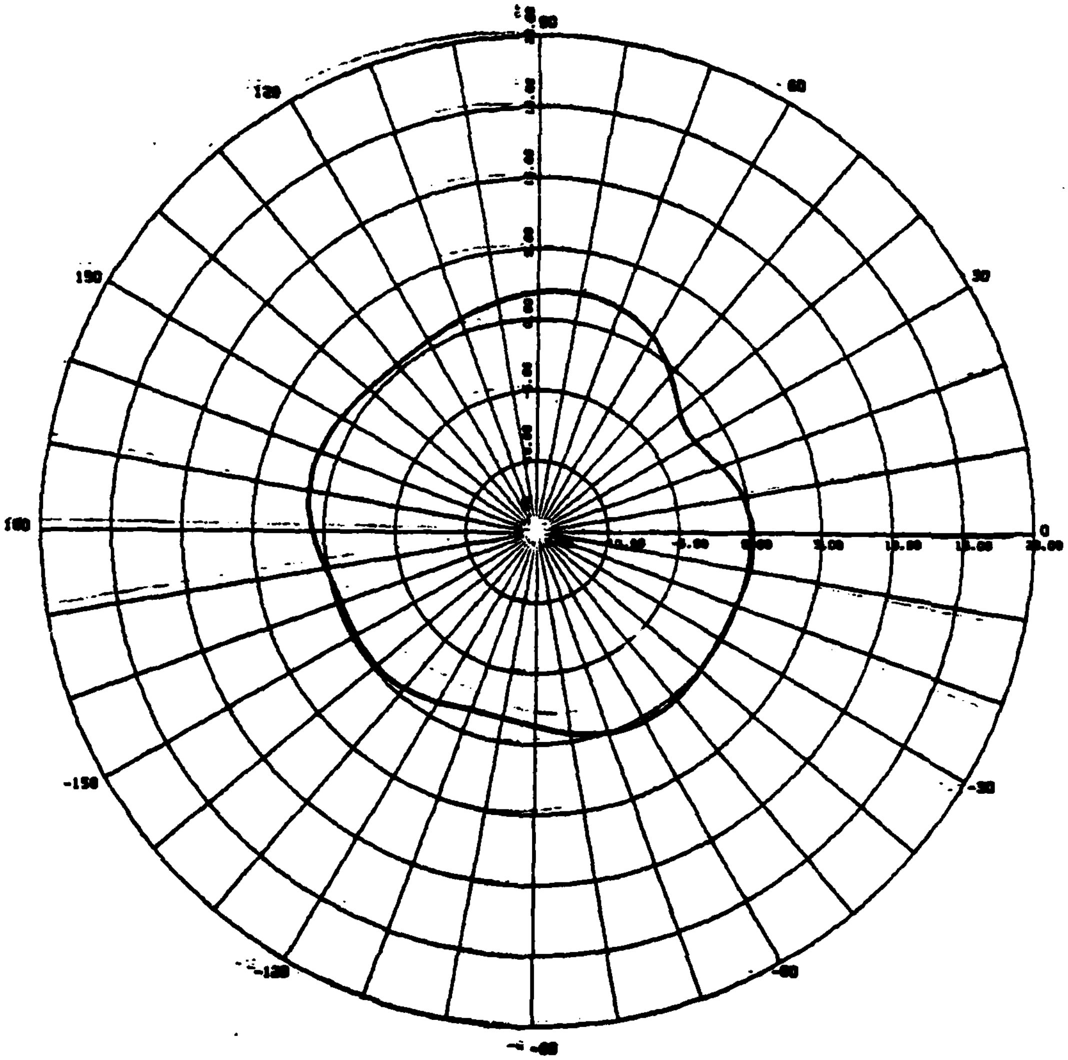
MAC-109 / PHI / THETA=80

SNOW / JEEP & TALA / 75 MHZ



MRC-109 / PHI / THETA=70

SNOW / JEEP & TRLR / 75 MHZ



MRC-109 / THETA / PHI=90

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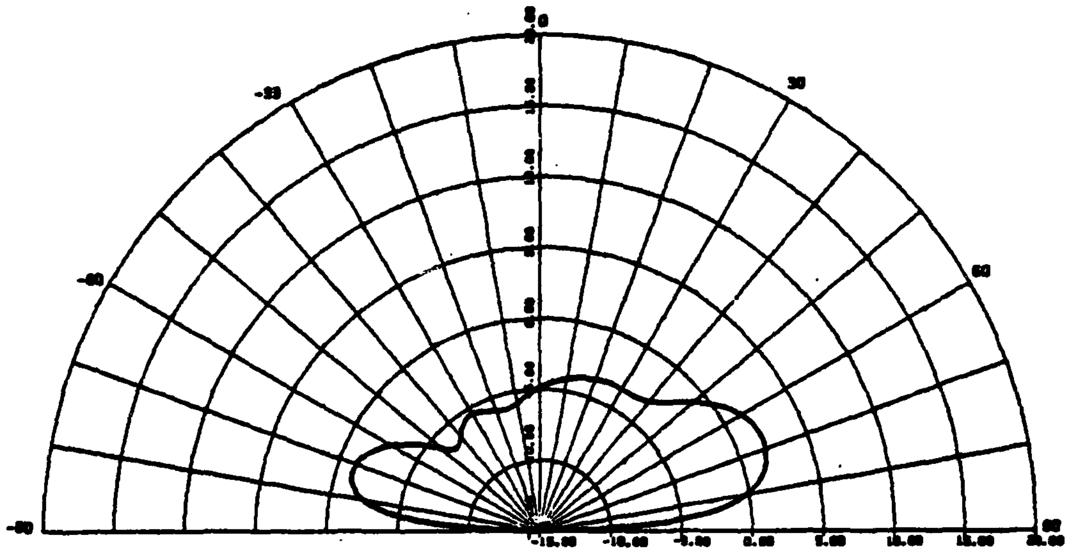
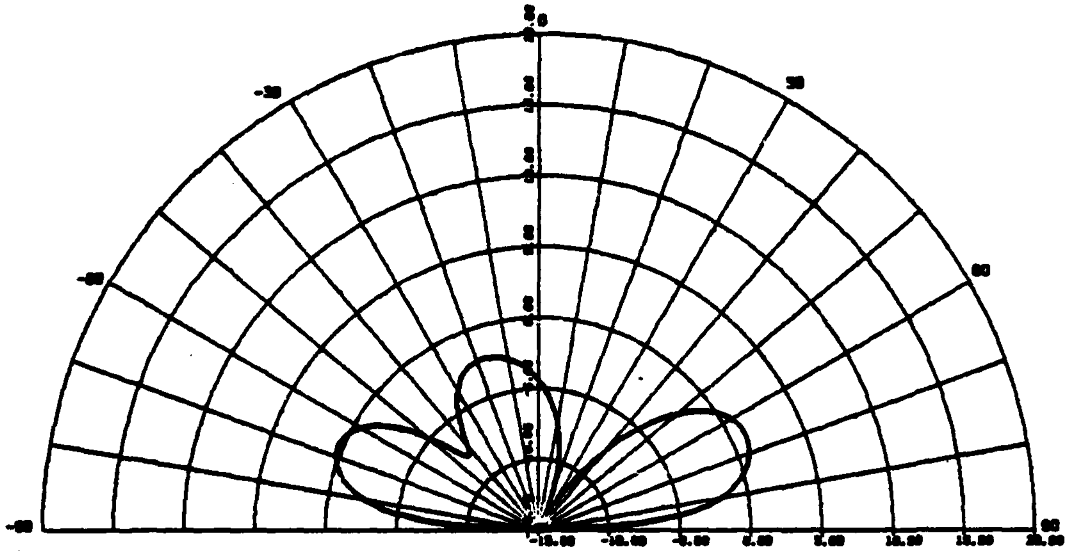


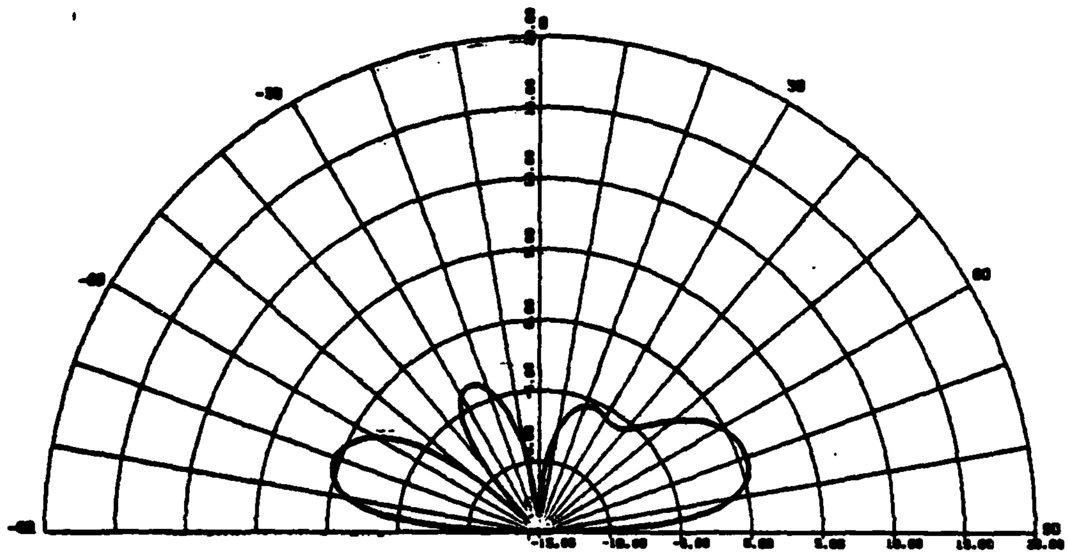
MAC-109 / THETA / PHI=180

SNOW / JEEP & TALA / 75 MHZ



MRC-109 / THETA / PHI=120

SNOW / JEEP & TRLR / 75 MHZ



APPENDIX C

This appendix contains a sample of the input geometry structure for each of the configurations in this study.

FILE: FCTEST2 DATA P1

```
CM*************************************************************
CM
CM
CM                 RC-292 APPROX
CM
CM                  T.M. CONFIGURED  LOW BAND   30.0 - 36.5
CM
CM
CM                  30.0 MHZ    HEIGHT  30 FT.
CM
CM
CM                      PASTORAL
CM
CE*************************************************************
GW1,18,0,0,0,0,0,9.15,0
GC0,0,.95,.02,.003
GW2,8,0,0,9.15,0,-1.51,6.947,.003
GW3,8,0,0,9.15,-1.3077,.755,6.947,.003
GW4,8,0,0,9.15,1.3077,.755,6.947,.003
GW5,8,0,0,9.15,0,0,11.32,0
GC0,0,.95,.003,.002
GE1
FR0,0,0,0,30.0,0
GN2,0,0,0,13.,0.005
EX0,5,2,00,10
RP0,21,1,1511,70,90,1,0
EN
```

FILE: FCTEST DATA P1

```
CM*************************************************************
CM
CM
CM                 RC-292 APPROX
CM
CM                  T.M. CONFIGURED  HIGH BAND   50.5 - 75.95
CM
CM
CM                  70.0 MHZ    HEIGHT  30 FT.
CM
CM                      PASTORAL
CM
CE*************************************************************
GW1,18,0,0,0,0,0,9.15,0
GC0,0,.95,.02,.003
GW2,8,0,0,9.15,0,-.9435,7.772,.003
GW3,8,0,0,9.15,-.817,.47175,7.772,.003
GW4,8,0,0,9.15,.817,.47175,7.772,.003
GW5,8,0,0,9.15,0,0,10.28,0
GC0,0,.95,.003,.002
GE1
FR0,0,0,0,70.0,0
EX0,5,2,00,10
GN2,0,0,0,13.,0.005
RP0,21,1,1511,70,90,1,0
EN
```

```
FILE: RC-292A  DATA     P1

CM**************************************************************
CM
CM                  RC-292 APPROX
CM
CM                  TROOP CONFIGURED  MID BAND
CM
CM                        40.0 MHZ   HEIGHT 30 FT
CM
CM                 PERFECT GROUND
CE**************************************************************
GW1,18,0,0,0,0,0,9.15,0
GC0,0,.95,.02,.003
GW2,8,0,0,9.15,0,-1.226,7.359504,.003
GW3,8,0,0,9.15,-1.061747,.613,7.359504,.003
GW4,8,0,0,9.15,1.061747,.613,7.359504,.003
GW5,8,0,0,9.15,0,0,10.8,0
GC0,0,.95,.003,.002
GE1
FR0,0,0,0,40.0,0
GN1
EX0,5,2,00,10
PL3,2,0,1
RP0,1,121,1511,30,-180,0,3
PL3,1,0,1
RP0,181,1,1511,-90,90,1
EN
```

```
FILE: VEH1      DATA      P1

CM**************************************************************
CM
CM
CM        AN/MRC-151  VEHICLE    "BASIC"     NO  ADS0,C5,TRLR
CM
CM          30 MHZ
CM
CM                                  S[illegible]
CM
CE**************************************************************
GW1,2,0,0,0,30,0,0,.5
GW2,2,15,0,0,15,0,28,.5
GW3,2,0,0,28,30,0,28,.5
GW4,2,30,0,28,30,0,0,.5
GW11,2,0,14,28,30,14,28,.5
GW12,3,15,0,28,15,42,28,.5
GW13,3,30,0,28,30,42,28,.5
GW14,2,0,28,28,30,28,28,.5
GW15,2,0,42,28,30,42,28,.5
GW20,2,30,42,0,30,14,28,.5
GW21,1,30,42,0,30,42,8,.5
GW22,2,30,42,0,30,42,28,.5
GW23,3,30,42,0,30,87,0,.5
GW24,3,30,42,0,30,87,0,.5
GW25,1,30,87,0,30,87,3,.5
GW26,1,30,87,3,30,91,28,.5
GW27,2,30,87,0,30,91,28,.5
GW28,4,30,91,28,30,121,28,.5
GW29,2,30,105,28,30,121,0,.5
GW30,2,15,42,0,15,42,28,.5
GW31,2,0,42,0,30,42,0,.5
GW32,2,15,0,0,15,42,0,.5
GW33,3,15,42,0,15,87,0,.5
GW34,2,0,87,0,30,87,0,.5
GW36,1,0,104,0,15,104,0,.5
GW37,2,15,87,0,15,121,0,.5
GW40,2,0,121,0,30,121,0,.5
GW41,4,30,121,0,30,121,28,.5
GW42,2,30,121,28,18,121,28,.5
GW43,2,18,121,28,15,121,14,.5
GW44,2,30,121,14,0,121,14,.5
GW45,2,30,121,7,0,121,7,.5
GW46,2,15,121,0,15,121,14,.5
GW48,1,30,121,21,16.5,121,21,.5
GW50,2,18,121,28,18,87,28,.5
GW51,2,18,87,28,30,91,28,.5
GW52,2,18,87,28,15,87,0,.5
GW53,2,18,104,28,15,104,0,.5
GX100,100
GM0,0,0,0,0,0,0,8
GS2
GE1
FR0,0,0,0,30,0
GN0,0,0,0,3.,,.00012
WG
```

```
FILE: VEH1      DATA      A1

NX
CM  NOW ADD THE ANTENNA CONFIG FOR AN/VRC-109
CM      ::::    NO  TRAILER   ::::
CM      ::::    NO WINDSHIELD  OR  CANVAS BRACE  :::
CM
CM
CM**************************************************************
CM
CM          AN/VRC-109
CM
CM                  SNOW
CM                                    30 MHZ
CE**************************************************************
GF
GW200,5,-30,121,23,-30,121,53,.5
GW201,5,-18,121,28,-26,121,53,.5
GW202,1,-26,121,53,-30,121,53,.5
GW203,1,-30,121,48,-24.4,121,48,.5
GW204,1,-30,121,38,-21.2,121,38,.5
GW205,5,-30,117,53,-30,105,23,.5
GW206,1,-30,121,53,-30,117,53,.5
GW207,1,-30,121,43,-30,114.6,43,.5
GW208,1,-30,121,38,-30,110.4,38,.5
GW210,4,-30,121,53,-30,121,31,0
GC0,0,1.4,.5,.5
GW211,6,-30,121,1,-30,121,173,.5
GM0,0,0,0,0,0,0,0
GS2
GE1
EX0,210,2,00,10
PT-3,1,1,1
PL3,2,0,1
RP0,1,121,1511,90,-180,0,3
PL3,2,0,1
RP0,1,121,1511,80,-180,0,3,
PL3,2,0,1
RP0,1,121,1511,70,-180,0,3
PL3,1,0,1
RP0,181,1,1511,-90,90,1
PL3,1,0,1
RP0,181,1,1511,-90,120,1
PL3,1,0,1
RP0,181,1,1511,-90,130,1
EN
```

FILE: VEH4   DATA   P1

```
CM*************************************************************
CM
CM
CM      AN/MRC-151 VEHICLE   WITH:  WINDSHIELD & CANVAS BRA
CM
CM       75 MHZ
CM
CM                           SNOW
CM
CE*************************************************************
GW1,2,.001,0,0,30,0,0,.5
GW2,2,15,0,0,15,0,28,.5
GW3,2,.001,0,28,30,0,28,.5
GW4,2,30,0,28,30,0,0,.5
GW11,2,.001,14,28,30,14,28,.5
GW12,3,15,0,28,15,42,28,.5
GW13,3,30,0,28,30,42,28,.5
GW14,2,.001,28,28,30,28,28,.5
GW15,2,.001,42,28,30,42,28,.5
GW20,2,30,42,0,30,14,28,.5
GW21,1,30,42,0,30,42,8,.5
GW22,2,30,42,8,30,42,28,.5
GW23,3,30,42,0,30,87,0,.5
GW24,3,30,42,8,30,87,8,.5
GW25,1,30,87,0,30,87,8,.5
GW26,1,30,87,8,30,91,28,.5
GW27,2,30,87,0,30,91,28,.5
GW28,4,30,91,28,30,121,28,.5
GW29,2,30,106,28,30,121,0,.5
GW30,2,15,42,0,15,42,28,.5
GW31,2,.001,42,0,30,42,0,.5
GW32,2,15,0,0,15,42,0,.5
GW33,3,15,42,0,15,87,0,.5
GW34,2,.001,87,0,30,87,0,.5
GW36,1,.001,104,0,15,104,0,.5
GW37,2,15,87,0,15,121,0,.5
GW40,2,.001,121,0,30,121,0,.5
GW41,4,30,121,0,30,121,28,.5
GW42,2,30,121,28,18,121,28,.5
GW43,2,18,121,28,15,121,14,.5
GW44,2,30,121,14,.001,121,14,.5
GW45,2,30,121,7,.001,121,7,.5
GW46,2,15,121,0,15,121,14,.5
GW48,1,30,121,21,15.5,121,21,.5
GW50,2,18,121,28,18,87,28,.5
GW51,2,18,87,28,30,91,28,.5
GW52,2,18,87,28,15,87,0,.5
GW53,2,18,104,28,15,104,0,.5
GW60,2,30,42,28,30,42,52,.5
GW61,2,.001,42,52,30,42,52,.5
GW65,3,30,91,28,29,117.833,52,.5
GW66,2,29.6666,99.9505,36,29,82.056,52,.5
GW67,2,29,82.056,52,.001,82.056,52,.5
GW68,2,29,117.833,52,.001,117.833,52,.5
GX100,100
```

```
FILE: VEH4      DATA      P1
GM0,0,0,0,0,0,0,8
GS2
GE1
FR0,0,0,0,75,0
GN0,0,0,0,3.,.00018
WG
NX
CM  NOW ADD THE ANTENNA CONFIG FOR AN/MRC-109
CM       ::::     NO  TRAILER     ::::
CM
CM
CM*****************************************************
CM
CM          AN/MRC-109
CM
CM                    SNOW
CM                                   75 MHZ
CE*****************************************************
GF
GW200,5,-30,121,28,-30,121,53,.5
GW201,5,-18,121,28,-26,121,53,.5
GW202,1,-26,121,53,-30,121,53,.5
GW203,1,-30,121,48,-24.4,121,48,.5
GW204,1,-30,121,38,-21.2,121,38,.5
GW205,5,-30,117,53,-30,106,28,.5
GW206,1,-30,121,53,-30,117,53,.5
GW207,1,-30,121,48,-30,114.8,48,.5
GW208,1,-30,121,38,-30,110.4,38,.5
GW210,4,-30,121,53,-30,121,81,0
GC0,0,1.4,.5,.5
GW211,6,-30,121,81,-30,121,173,.5
GM0,0,0,0,0,0,0,8
GS2
GE1
EX0,210,2,00,10
PL3,2,0,1
RP0,1,121,1511,90,-180,0,3
PL3,2,0,1
RP0,1,121,1511,80,-180,0,3,
PL3,2,0,1
RP0,1,121,1511,70,-180,0,3
PL3,1,0,1
RP0,181,1,1511,-90,90,1
PL3,1,0,1
RP0,181,1,1511,-90,120,1
PL3,1,0,1
RP0,181,1,1511,-90,180,1
EN
```

```
CM***********************************************************************
CM
CM
CM        AN/MRC-151 VEHICLE   WITH:  WINDSHIELD & CANVAS BRA(
CM
CM                                             AND  TRAILER
CM         30.0 MHZ
CM
CM
CM      PERFECT GROUND
CM
CE***********************************************************************
GW1,2,0,0,0,30,0,0,.5
GW2,2,15,0,0,15,0,28,.5
GW3,2,0,0,28,30,0,28,.5
GW4,2,30,0,28,30,0,0,.5
GW11,2,0,14,28,30,14,28,.5
GW12,3,15,0,28,15,42,28,.5
GW13,3,30,0,28,30,42,28,.5
GW14,2,0,28,28,30,28,28,.5
GW15,2,0,42,28,30,42,28,.5
GW20,2,30,42,0,30,14,28,.5
GW21,1,30,42,0,30,42,8,.5
GW22,2,30,42,8,30,42,28,.5
GW23,3,30,42,0,30,87,0,.5
GW24,3,30,42,8,30,87,8,.5
GW25,1,30,87,0,30,87,8,.5
GW26,1,30,87,8,30,91,28,.5
GW27,2,30,87,0,30,91,28,.5
GW28,4,30,91,28,30,121,28,.5
GW29,2,30,105,28,30,121,0,.5
GW30,2,15,42,0,15,42,28,.5
GW31,2,0,42,0,30,42,0,.5
GW32,2,15,0,0,15,42,0,.5
GW33,3,15,42,0,15,87,0,.5
GW34,2,0,87,0,30,87,0,.5
GW36,1,0,104,0,15,104,0,.5
GW37,2,15,87,0,15,121,0,.5
GW40,2,0,121,0,30,121,0,.5
GW41,4,30,121,0,30,121,28,.5
GW42,2,30,121,28,18,121,28,.5
GW43,2,18,121,28,15,121,14,.5
GW44,2,30,121,14,0,121,14,.5
GW45,2,30,121,7,0,121,7,.5
GW46,2,15,121,0,15,121,14,.5
GW48,1,30,121,21,16.5,121,21,.5
GW50,2,18,121,28,18,87,28,.5
GW51,2,18,87,28,30,91,28,.5
GW52,2,18,87,28,15,87,0,.5
GW53,2,18,104,28,15,104,0,.5
GW60,2,30,42,28,30,42,52,.5
GW61,2,0,42,52,30,42,52,.5
GW65,3,30,91,28,29,117.333,52,.5
GW66,2,29.6666,99.9505,36,29,82.056,52,.5
GW67,2,29,82.056,52,0,82.056,52,.5
```

```
GW68,2,29,117.833,52,0,117.833,52,.5
GW70,2,0,121,0,12,145,0,.5
GW71,2,0,145,24,24,145,24,.5
GW72,6,24,145,24,24,217,24,.5
GW73,2,0,217,24,24,217,24,.5
GW74,3,12,145,0,12,217,0,.5
GW75,2,0,169,0,24,169,0,.5
GW76,2,0,145,0,24,145,0,.5
GW77,2,0,217,0,24,217,0,.5
GW78,2,24,145,0,24,145,24,.5
GW79,2,24,217,0,24,217,24,.5
GW80,2,24,145,0,24,169,0,.5
GW81,1,24,205,0,24,217,0,.5
GW82,1,24,205,0,24,193,12,.5
GW83,1,24,169,0,24,181,12,.5
GW84,1,24,181,12,24,193,12,.5
GW85,2,12,145,0,12,145,24,.5
GX100,100
GM0,0,0,0,0,0,0,5
GS2
GE1
FR0,0,0,0,30,0
GN1
WG
NX
CM   NOW ADD THE ANTENNA CONFIG FOR AN/MRC-109
CM
CM
CM
CM*******************************************************
CM
CM          AN/MRC-109
CM
CM      PERFECT GROUND
CM                                  30 MHZ
CE*******************************************************
GF
GW200,5,-30,121,23,-30,121,53,.5
GW201,5,-18,121,28,-26,121,53,.5
GW202,1,-26,121,53,-30,121,53,.5
GW203,1,-30,121,43,-24.4,121,48,.5
GW204,1,-30,121,33,-21.2,121,38,.5
GW205,5,-30,117,53,-30,106,28,.5
GW206,1,-30,121,53,-30,117,53,.5
GW207,1,-30,121,43,-30,114.8,48,.5
GW208,1,-30,121,38,-30,110.4,38,.5
GW210,4,-30,121,53,-30,121,81,0
GC0,0,1.4,.5,.5
GW211,6,-30,121,81,-30,121,173,.5
GW212,2,0,87,0,0,121,0,.5
GW213,2,0,121,0,0,121,14,.5
GM0,0,0,0,0,0,0,8
GS2
GE1
EX0,210,2,00,10
```

```
PL3,2,0,1
RPO,1,121,1511,90,-180,0,3
PL3,2,0,1
RPO,1,121,1511,80,-180,0,3,
PL3,2,0,1
RPO,1,121,1511,70,-180,0,3
PL3,1,0,1
RPO,181,1,1511,-90,90,1
PL3,1,0,1
RPO,181,1,1511,-90,120,1
PL3,1,0,1
RPO,181,1,1511,-90,180,1
EN
```

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